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A Statistical Analysis of Hydrologic Drought in the Humboldt Basin, Nevada

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Hydrology

by

Richard Joseph Pautsch

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ABSTRACT

A STATISTICAL ANALYSIS OF HYDROLOGIC DROUGHT IN THE HUMBOLDT BASIN, NEVADA

Richard J. Pautsch

The central question addressed by this thesis concerns the randomness of Humboldt Basin precipitation and streamflow data during drought periods, both in terms of cyclical behavior and in terms of clusters of wet and dry years. If the data is not random, but systematic, then the study of past droughts may provide insights which can help man to anticipate future droughts and their durations. If the data is random, then an analysis of the statistics of past droughts can help man to gauge the precipitation and streamflow extremes which can reasonably be expected to occur within given time frames, but cannot provide insight into their timing.

This study will also make estimates of extremes to be expected and the probable recurrence intervals of these extremes. On a limited basis, it will attempt to assess the impact of such extremes on agricultural production along the Humboldt River.

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INTRODUCTION

DROUGHT

The phenomenon of drought has received remarkably little study by the scientific community, particularly when contrasted with its counterpart, floods. As Yevjevich (1967) stated, "Of all the main problems of hydrometeorology and hydrology, the properties of severe continental droughts are likely to be the least known." This lack of knowledge extends from incomplete understanding of the causes of drought to weaknesses in the application of statistical methods and frequency analysis to drought and even to uncertainty as to when a drought has started and stopped.

This uncertainty about drought is reflected in the varied definitions of drought. There is no standard definitions of drought. For the purposes of this investigation, two different interpretations of drought will be employed. First, as a basis for the statistical analysis of the raw precipitation and streamflow data which forms the foundation of this study, drought will be equated with an annual precipitation or streamflow value below the historic mean of that particular data set. Such events, particularly when they are sequential and result in a significant cumulative deficit, will be the ones analyzed for their statistical characteristics in the first part of this study.

This definition, however, does not go far enough when the needs of man are taken into consideration. Drought is not solely a natural and statistical phenomenon, but it is one determined by man's needs for water compared to natural supplies. Thus, the second segment of this study will look at man's level of water use particularly within the agricultural sector in the Humboldt Basin and compare this use with historically available supplies of water. For the purpose of this analysis, drought will be defined as "a shortage of water supply compared to established demand."

While drought as defined by deficiencies in precipitation and streamflow is definitely interrelated with deficiencies in the groundwater system, a consideration of drought effects on groundwater is beyond the scope of this paper. Though potential future use of groundwater may be much greater, the U.S. Department of Agriculture (1966) found annual groundwater use for beneficial purposes (the majority of which was consumption by grazing-land phreatophytes) to be only 10% of total water use in the basin. Interested readers are referred to the Groundwater Resources Reconnaissance Series (1961-1976) published by the State of Nevada with the assistance of the U.S.G.S. for an analysis of groundwater systems in the Humboldt Basin.

STUDY AREA

The Humboldt River Basin lies in northern Nevada within both the Great Basin and the Basin and Range physiographic province. It is the largest river basin in the state of Nevada, comprising an area of approximately 16,600 square miles, or roughly 15% of the area of Nevada. Figure 1 shows the location of the basin in Nevada.

The Humboldt River originates in northeastern Nevada, where peaks in the Ruby Mountains rise as high as 11,349 feet, and flows in a generally westward direction along a 300 mile course to the Humboldt Lakes, which lie below 3900 feet in elevation. The highest point in the basin is Arc Dome (elevation 11,788 feet) in central Nevada in the Reese River sub-basin. However, this sub-basin rarely contributes water to the Humboldt River main stem, and thus the Ruby Mountains of northeastern Nevada, which contribute over half the total flow of the river in a typical year, can more properly be called the headwaters of the Humboldt. Figure 2 shows the sub-basins of the Humboldt Basin and their contributions to main stem streamflow. Main stem flow averages about 300 cfs over the course of the year in the river's lower reaches, with marked seasonal variation.

Topography in the basin is typical of the Basin and Range Province, with mountain chains regularly alternating with flat alluvium-filled valleys. Many of the valleys

FIGURE 1: LOCATION OF THE HUMBOLDT RIVER BASIN AND OF THE GAGING STATIONS

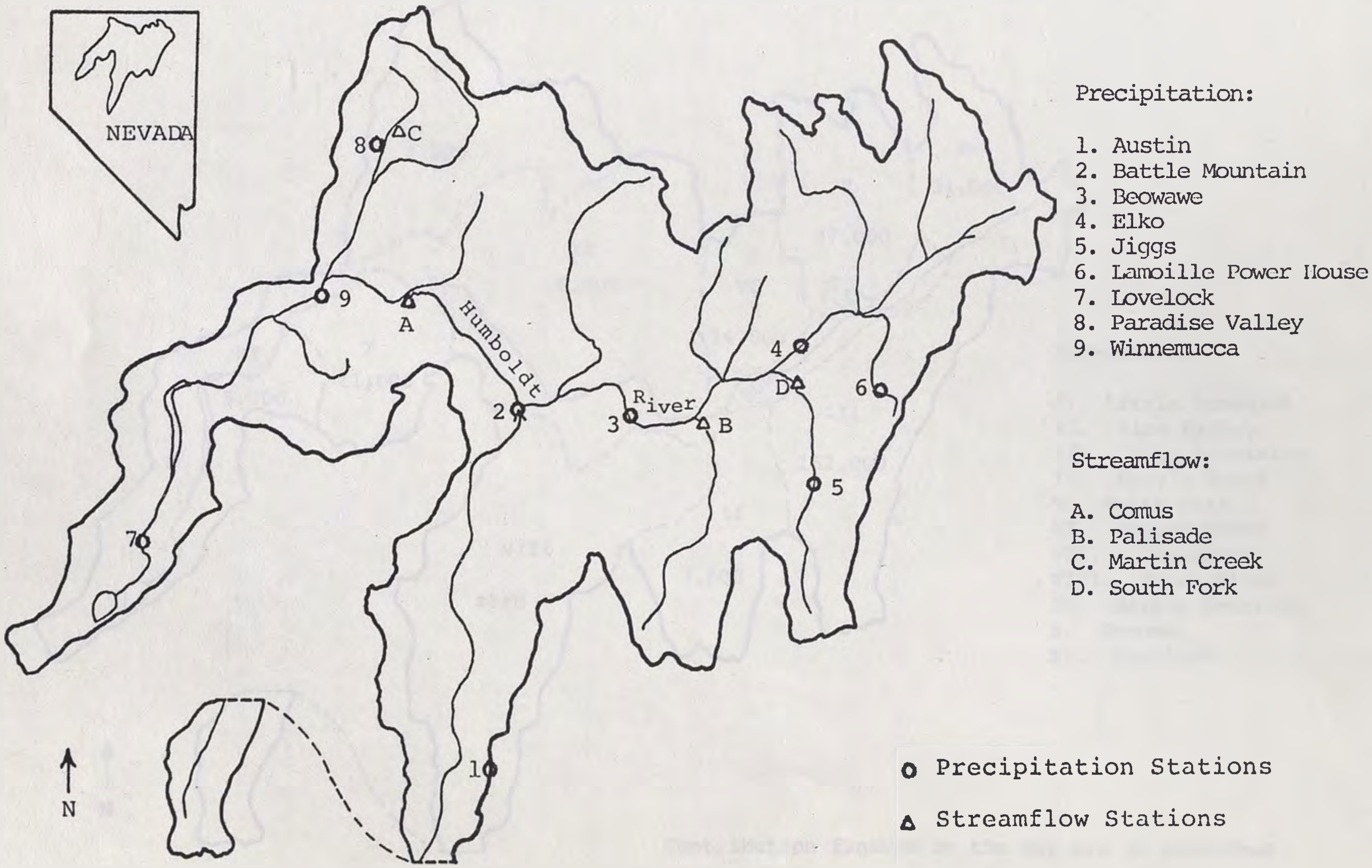
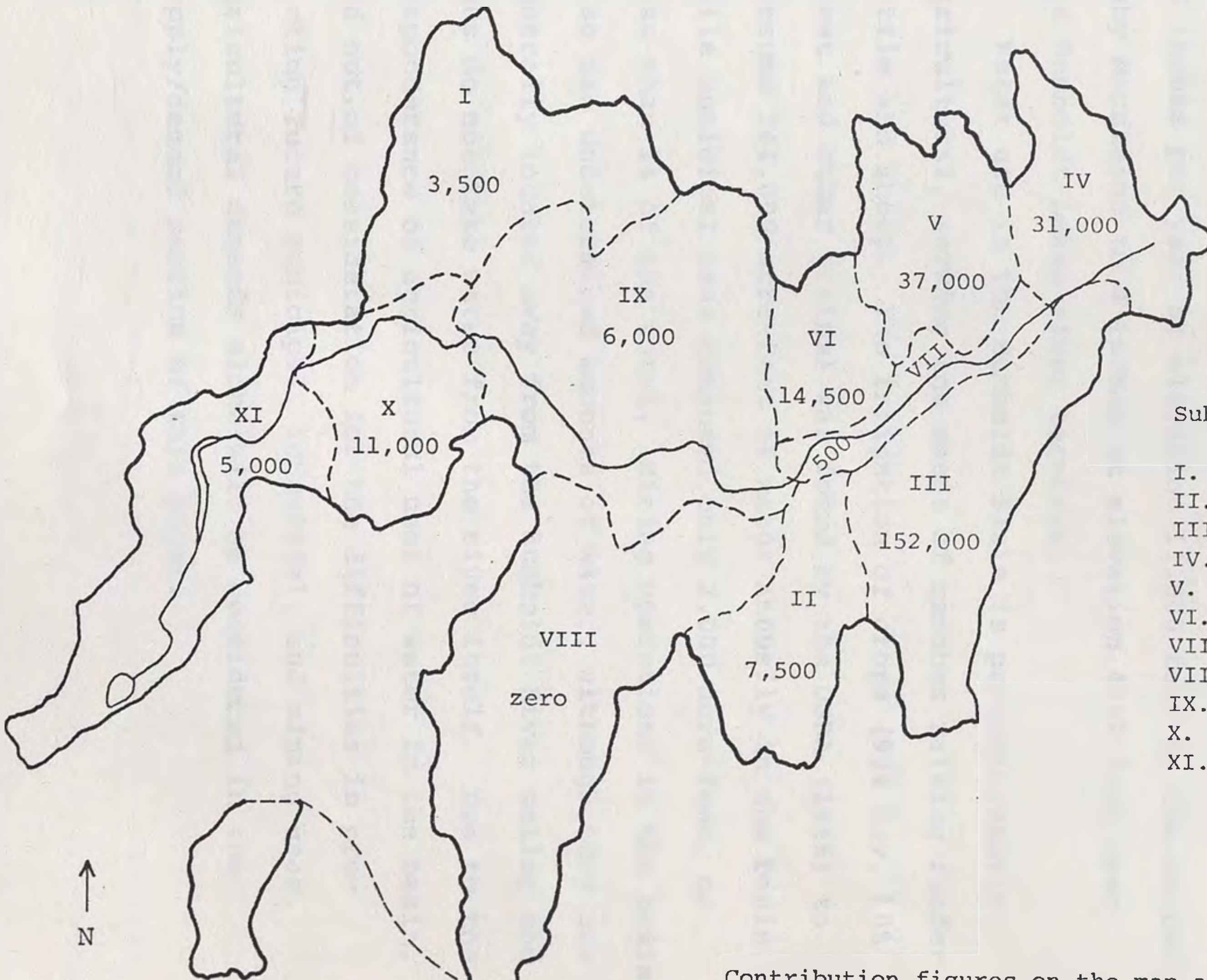


FIGURE 2: SUB-BASINS AND THEIR CONTRIBUTIONS TO MAIN STEM FLOW



Sub-basins:

I. Little Humboldt
II. Pine Valley
III. Ruby Mountains
IV. Mary's River
V. North Fork
VI. Maggie Creek
VII. Elko Reach
VIII. Reese River
IX. Battle Mountain
X. Sonoma
XI. Lovelock

Contribution figures on the map are in acre-feet.

normally serve as sinks for Humboldt tributaries flowing into them, and thus only rarely contribute water to the Humboldt itself. The prononuced alternation of valleys and mountains also leads to a high variability of precipitation within relatively limited areas due to orographic lifting. Average precipitation ranges from an estimated 50 inches per year at elevation 11,000 feet in the eastern Ruby Mountains to 4 inches at elevation 4000 feet near the Humboldt Lakes river terminus.

Water use in the Humboldt Basin is predomininantly agricultural, serving the needs of ranches raising feeder cattle and sheep. The irrigation of crops (90% hay, 10% wheat and other grains) was found by the USDA (1966) to consume 344,000 acre-feet of water annually in the basin, while municipal uses consumed only 2,000 acre-feet, or less than 1% of the total. Mining operations in the basin also use undetermined amounts of water, although they are generally located away from the Humboldt River valley and thus do not take water from the river itself. Due to the preponderance of agricultural uses of water in the basin, and out of consideration for the difficulties in predicting future municipal, industrial, and mining uses, agricultural demands alone will be considered in the supply/demand section of this paper.

STATEMENT OF OBJECTIVES

This study will examine the statistical behavior of precipitation and streamflow data in the study area in order to draw systematic inferences concerning the delineation of drought. The study be necessity will be constrained to the consideration of water used in the agricultural sector only.

ADEQUACY OF THE DATA

Houghton (1969) states, in regard to the Great Basin, that "This area, more than any other part of the contiguous United States, suffers from a lack of adequate precipitation records." In the sparsely settled Great Basin and Humboldt Basin, relatively few precipitation gaging stations exist, and, of those which do exist, few have continous records of a duration long enough to be suitable to a statistical study of precipitation, particularly a study of precipitation extremes such as this one. The problems associated with a sparse gaging network become acute in regions such as the Great Basin, where the large number of mountain ranges greatly increases the areal variability of precipitation, and where the predominant summer precipitation form, the thunderstorm, brings very spotty heavy precipitation to scattered small areas of the basin. Furthermore, in the high mountain areas where precipitation is heaviest and where the majority of the Humboldt River main stem flow originates, long-term precipitation records simply do not exist. A total of nine stations were found which had precipitation data adequate for the purposes of this study.

The relatively few streams in the Humboldt Basin are more easily and adequately covered by a network of stream gages, but most of the existing gages have been installed since World War II and thus do not provide an adequate length of data for a statistically valid study of low-flow extremes. Tables 1 and 2 list the nine precipitation and four streamflow gaging stations in the Humboldt Basin which provided a sufficient length and continuity of record to be useful in this study. Tables 1 and 2 also list the years of record for each station, the number of missing years, the station elevation, and other factors affecting the reliability of the data, including changes in station location and name. Figure 1 shows the locations of the precipitation and streamflow stations which provided the raw data for this study.

It should be noted that streamflow data is given on the basis of water years (October to September) while precipitation data is given on the basis of clendar years. As all raw data employed was given in English units, all figures in this paper are also given in English units. Metric conversion factors are given in Appenix A.

TABLE 1

DATA UTILIZED IN THE STUDY, PRECIPITATION

Calendar Year Basis

STATION NAME	YEARS OF RECORD (number of years)	NUMBER OF MISSING YEARS (years)	ELEVATION (feet)	OTHER FACTORS AFFECTING DATA
Austin	1890-1976 (82)	5 (1899,1909, 1910,1944,1949)	6594	
Battle Mountain	1870-1976 (105)	2 (1944,1948)	4513	Station at RR depot 1870-1943. Moved to airport, 1945.
Beowawe	1870-1976 (99)	8 (1939,1943, 1944,1947,1948, 1949,1951,1952)	4695	Station moved 100 feet in 1949 and 100 feet in 1950.
Elko	1870-1976 (107)	0	5077	Official U.S. Weather Bureau Station
Jiggs	1910-1969 (57)	3 (1943,1944, 1945)	5800	6 mi. SSW of Jiggs, 1910-1923. Known as Skelton and Hylton.
			5650	3 mi. SSE of Jiggs, 1923-1943. Known as Hylton.
			5465	At Jiggs Post Office. Moved 500 feet in 1946.
			5450	Moved 545 feet in 1952.

TABLE 1,

STATION NAME	YEARS OF RECORD (number of years)	NUMBER OF MISS-ING YEARS (years)
Lamoille Power House	1916-1971 (55)	1 (1951)
Lovelock	1891-1976 (82)	4 (1907,1915, 1936,1967)
Paradise Valley, 1 NW	1922-1976 (49)	6 (1948,1949, 1950,1951,1953, 1954)
Winnemucca	1871-1976 (106)	0

continued

ELEVATION (feet)	OTHER FACTORS AFFECTING DATA
6290	3 mi. S of Lamoille. In narrow canyon which might affect data.
3977	Moved several times, but no more than a few hundred feet each time.
5000	In a foothill canyon 3.8 mi. WNW from 1922 to 1925.
4344	Official U.S. Weather Bureau Station after 1884.

TABLE 2

DATA UTILIZED IN THE STUDY, STREAMFLOW

Water Year Basis (October to September)

STATION NAME	YEARS OF RECORD (number of years)	NUMBER OF MISSING YEARS (years)	ELEVATION (feet)	OTHER FACTORS AFFECTING DATA
Humboldt River, Comus	1895-1926 1946-1976 (62)	1 (1910) plus 1927-1945	4350	12,100 sq. mile drainage area. Irrigation diversions above station. Data for 1895,1905, 1923,1924,1925,1926, and 1946 estimated by USGS.
Humboldt River, Palisade	1912-1976 (65)	0	4826	5010 sq. mile drainage area. Irrigation diversions for approximately 150,000 acres upstream.
South Fork Humboldt River, 10 miles SW of Elko	1897-1973 (69)	8 (1910,1919, 1920,1923,1933, 1934,1935,1936)	5100	1150 sq. mile drainage area. Many irrigation diversions above station. Data for 1904, 1921,1922, and 1927 estimated by USGS.
Martin Creek, near Paradise Valley	1922-1976 (55)	0	4700	172 sq. mile drainage area.

CLIMATOLOGY

PRECIPITATION SOURCES FOR THE HUMBOLDT BASIN

Since drought results from a decrease in precipitation, an analysis of drought might well begin with a brief climatological analysis of the sources of this precipitation. Precipitation in the Humboldt Basin is derived from three distinct sources. These sources are, in order of importance: Pacific, Continental, and Gulf (Houghton, Sakamoto, and Gifford, 1975; Houghton, 1969).

Pacific precipitation is controlled by the Aleutian Low, where storms originate, and the Pacific High (North Pacific Anticyclone) which may prevent storm systems from reaching the Humboldt Basin.

Most Pacific storm systems originate in a frontal zone in the western Pacific where continental polar air from central Asia comes together with warmer, moisture-laden oceanic Pacific air. In this area the persistant Aleutian Low develops. The Aleutian Low reaches its maximum intensity and extent in January, and virtually disappears from May to September. The number and intensity of storm systems developing in the region and subsequently reaching North America are determined by the temperature and flow of air from northern Asia and by the prevailing water temperatures in the northwest Pacific. Transitory frontal systems trailing southward from low pressure systems which move eastward from the Aleutian Low along jet stream storm tracks bring most of the Pacific precipitation to the Humboldt Basin.

The path of the jet stream determines how close these moisture-laden low pressure systems come to the Humboldt Basin. On rare occasions, the jet stream brings low-pressure systems directly over the basin and above average precipitation results. On other occasions, the jet stream is far from the basin and the influence of lows moving through the western U.S. is less effective in bringing precipitation to the Humboldt Basin. Obviously, then, anything causing the jet stream winter storm track to move farther from the basin also results in less precipitation for the basin.

The presence of the Pacific High determines whether or not the jet stream will bring storms generated in the Aleutian Low close enough to Nevada to bring precipitation to the Humboldt Basin. The Pacific High is a ridge of high pressure which is usually centered between 30 and 40 degrees North and between 140 and 150 degrees West. It extends to the top of the troposphere and thus effectively diverts weather systems approaching from the west. In a normal year, the Pacific High reaches its maximum extent in August, when virtually no moisture of Pacific origin falls in the Humboldt Basin, then retreats southeastward to its minimum extent in January, when virtually all precipitation falling in the Humboldt Basin is of Pacific origin.

The failure of the Pacific High to weaken and retreat southward with the coming of winter has been directly responsible for extended Pacific coast and Humboldt Basin droughts, including the most recent drought of 1976-1977. Storms which would normally bring precipitation to the Humboldt Basin are instead diverted to the north by the persisting high. Dr. Jerome Namias of the Scripps Institute for Oceanography has linked abnormal persistance of the Pacific High, and accompanying west coast drought, to changes in Pacific Ocean water temperatures. Namias, analyzing the 20,000 readings taken each month of northern and central Pacific water surface temperatures, found 1976 central Pacific water surface temperatures 2° C below normal, and California coastal temperatures 2° C above normal. In the fall of 1976 western Pacific water temperatures were the coldest ever recorded. This combination of adjacent bodies of cold and warm water would tend to anchor the high pressure system which diverted Pacific storm systems around California for the past two winters. The warm water buildup off the California coast has been hypothetically linked to the absence of the cold Peruvian current, which in turn has been linked to a weakening in the southeast tradewinds. The cold water buildup in the western Pacific has been weakly linked to increased cloud cover or cooling winds.

In late autumn of 1977, the ocean temperatures began to return to normal, the high pressure system off the coast began to retreat, and heavier than normal precipitation began to fall, first in Washington, then in Oregon, and finally in California, paralleling the retreat of the Pacific High. A better understanding of the relationship between Pacific water temperatures and atmospheric circulation patterns may one day lead to an ability to predict both the onset and the retreat of drought in Nevada.

Of secondary importance to the dominant Pacific storm systems are Continental systems, or those originating within the Great Basin itself. The Great Basin has the highest frequency of both cyclone and anti-cyclone (low and high pressure system) genesis in the northern hemisphere (Klein, 1957), and both types of systems influence the amount of precipitation falling within the Humboldt Basin.

Great Basin highs form most frequently in winter in southern Idaho and northeastern Nevada as cold, stagnant air masses near the surface. These high pressure systems can result in the diversion of Pacific storm systems around the area, and thus result in decreased precipitation in the same manner as the presence of the Pacific High. Although these high-pressure systems are generally short-lived, they are occassionally persistent enough to cause prolonged winter periods of fair weather and no precipitation. In such a case, the shortfall of precipitation would be most pronounced within Nevada in the northeastern Humboldt Basin area.

Great Basin lows, on the other hand, result in a significant amount of precipitation in the Great Basin, particularly in northern Nevada and the Humboldt Basin. These lows are continental cyclones which originate most frequently in the lee of the highest Sierra Nevada peaks in the vicinity of Tonopah (hence their cognomen, "Tonopah Lows"). They then move directly across Nevada, often creating the conditions necessary to trigger precipitation of moisture carried into Nevada from the Pacific or Gulf, or, possibly, of moisture resulting from evaporation within the basin itself following spring snowmelt (Stidd, 1968).

Great Basin lows are most prominent in late spring, with a secondary associated rainfall peak in October. It is because of these systems that May is one of the wettest months in the Humboldt Basin. Thus, the frequency of generation of these lows, and the amount of precipitable moisture they encounter in their progress across the state, is very significant in determining water supplies in the Humboldt Basin.

The third important source of precipitation in the Humboldt Basin is moist air arriving from the Gulf of

Mexico. While the Pacific component is most important in the winter, and the Great Basin lows achieve primacy in the spring and fall, the Gulf thunderstorm component results in most of the July and August precipitation and is insignificant during most of the rest of the year.

The approach of summer brings with it a shift in the general patterns of northern hemisphere atmospheric circulation. The Pacific storm track moves far northward to a location where it no longer influences the Great Basin. Meanwhile, a mid-continent summer high develops. Warm, moist air from the Gulf of Mexico and occassionally the Gulf of California moves northwestward along the boundary of this high and into the Great Basin. Local convective activity may lift this moist Gulf air to produce summer thunderstorms. This effect is most significant in southern Nevada, but can also bring unpredictably large amounts of rain to the Humboldt Basin--one such event dumped 4 inches of rain on Elko in one day in August, 1970.

CORRELATIONS BETWEEN HISTORIC DROUGHTS AND SOURCE DEFICIENCIES

Houghton (1969) divided 1962-1963 precipitation data from each recording gage station in the Great Basin into Pacific, Continental, and Gulf components. For the general area of the Humboldt Basin and for the two years studied (1962 was generally a drier than average year and

1963 a much wetter than average year in the Humboldt Basin), he found that 64% of precipitation was attributable to the Pacific component, 29% to the Continental component, and 7% to the Gulf component.

Houghton analyzed the Elko precipitation data for these years in particular detail. Table 3 shows the percentage of monthly rainfall contributed by each of the three components at Elko in 1962-1963. Note that 91% of January precipitation is of Pacific origin, 92% of June precipitation is of Continental origin, and 94% of August precipitation is of Gulf origin. Assuming these percentage values to be typical of the period of record, it is possible to analyze periods of drought for deficiencies in particular precipitation sources based on precipitation deficiencies for these indicator months.

Application of this type of analysis to historical Elko droughts resulted in the delineation of varying source deficiencies for different drought periods. Results of this analysis are compiled in Table 4 for the droughts of 1870 to 1888, 1923 to 1929, and 1958 to 1962. For example, using January, June, and August as indicator months for Pacific, Continental, and Gulf components respectively, marked deficiencies in the Continental and Gulf components occur in the 1870-1888 drought, marked deficiencies in the Gulf component and lesser deficiencies in the Pacific and Continental components show up in the

TABLE 3

MONTHLY PRECIPITATION COMPONENTS, ELKO, 1962-1963

COMPONENT	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR
Pacific	91%	84%	74%	39%	18%	8%	3%	3%	15%	39%	62%	88%	52%
Continental	9%	16%	26%	61%	82%	92%	15%	3%	41%	61%	38%	12%	39%
Gulf	0%	0%	0%	0%	0%	0%	82%	94%	44%	0%	0%	0%	9%

TABLE 4

SOURCE COMPONENT DEFICIENCIES IN ELKO DROUGHTS

Per cent of 1962-1963 mean for the component

	1870-1888	1923-1929	1958-1962
January (Pacific)	76%	66%	52%
June (Continental)	27%	66%	55%
August (Gulf)	13%	20%	115%
Period (per cent of normal)	59%	78%	80%

1923-1929 drought, and deficiencies in the Pacific and Continental components (with a surplus in the Gulf component) characterize the 1958-1962 drought.

This method shows promise as a means of analyzing the climatological nature of historic droughts. A data base significantly longer than the 1962-1963 period used by Houghton for his identification of component contributions would first need to be developed, however.

MAGNITUDE OF HISTORIC DROUGHTS

BASIC STATISTICS OF HISTORIC DROUGHTS

Table 5 gives basic statistics -- mean, standard deviation, skew, wettest and driest years of record, range from the wettest to the driest recorded year, and shortfall below mean of the greatest recorded drought in terms of number of times mean annual precipitation -- for the nine precipitation stations studied. Table 6 gives the same statistics for the four streamflow stations studied.

The precipitation data shows that mean annual precipitation varies from 4.88 inches in Lovelock to 18.04 inches at Lamoille Power House. This variation is attributable primarily to elevation and secondarily to an increase in precipitation going from west to east in the Humboldt Basin. Although the lowest and highest standard deviations correspond with the lowest and highest precipitation magnitudes (a low of 2.17 at Lovelock and a high of 4.51 at

TABLE 5

BASIC PRECIPITATION STATISTICS

	Austin	Battle Mt.	Beowawe	Elko	Jiggs	Lamoille	Lovelock	Paradise Valley	Winnemucca
MEAN, inches	12.48	6.84	6.89	8.90	12.01	18.04	4.88	9.15	8.37
STANDARD DEVIATION, inches	3.44	2.33	2.83	3.49	2.59	4.51	2.17	2.76	2.41
SKEW	.46	.76	.89	.38	.24	.11	.67	.52	.74
WETTEST YEAR, inches	21.07	14.03	14.92	18.94	17.73	29.16	11.93	17.46	18.38
DRIEST YEAR, inches	5.90	2.40	2.10	0.94	6.74	8.80	0.85	4.30	3.13
RANGE, WETTEST YEAR TO DRIEST YEAR, inches	15.17	11.63	12.82	18.00	10.99	20.36	11.08	13.16	15.25
SHORTFALL OF GREATEST RECORDED DROUGHT, number of times historic mean	3.29	5.99	5.66	7.75	2.75	2.11	7.17	2.51	3.23

TABLE 6

BASIC STREAMFLOW STATISTICS

	Palisade	Comus	South Fork	Martin Creek
MEAN, cfs	367.46	286.49	126.27	31.73
STANDARD DEVIATION, cfs	223.52	212.42	60.01	15.88
SKEW	.74	1.06	.33	1.03
HIGHEST ANNUAL FLOW, cfs	877	950	270	88.1
LOWEST ANNUAL FLOW, cfs	34.8	24.0	16.3	8.2
RANGE, HIGHEST TO LOWEST ANNUAL FLOW, cfs	842.2	926.0	253.7	79.9
SHORTFALL OF GREATEST RECORDED DROUGHT, number of times historic mean	6.55	6.52	5.82	3.78

Lamoille Power House), standard deviations at the other seven precipitation stations do not correspond with the relative precipitation magnitudes of the stations. Skew values generally vary inversely with mean precipitation, from a high of .89 at Beowawe to a low of .11 at Lamoille. Skew values are also higher for stations in the western part of the basin than in the eastern part.

Record low precipitation for a calendar year was 0.85 inches at Lovelock in 1905, followed closely by 0.94 inches at Elko in 1872. The highest precipitation amount recorded in a year for the study stations was 29.16 inches at Lamoille Power House. The range in precipitation from the driest to the wettest year varied from 10.99 inches at Jiggs (with a 57 year data base) and 11.08 inches at Lovelock to 20.36 inches at Lamoille and 18.00 inches at Elko. Only at Jiggs was the range in recorded annual precipitation values less than the mean precipitation, an indication of relatively low variability at this station. In contrast, at Lovelock, which also had a low absolute variation in annual precipitation range, the range in precipitation magnitudes was 2.3 times mean annual precipitation.

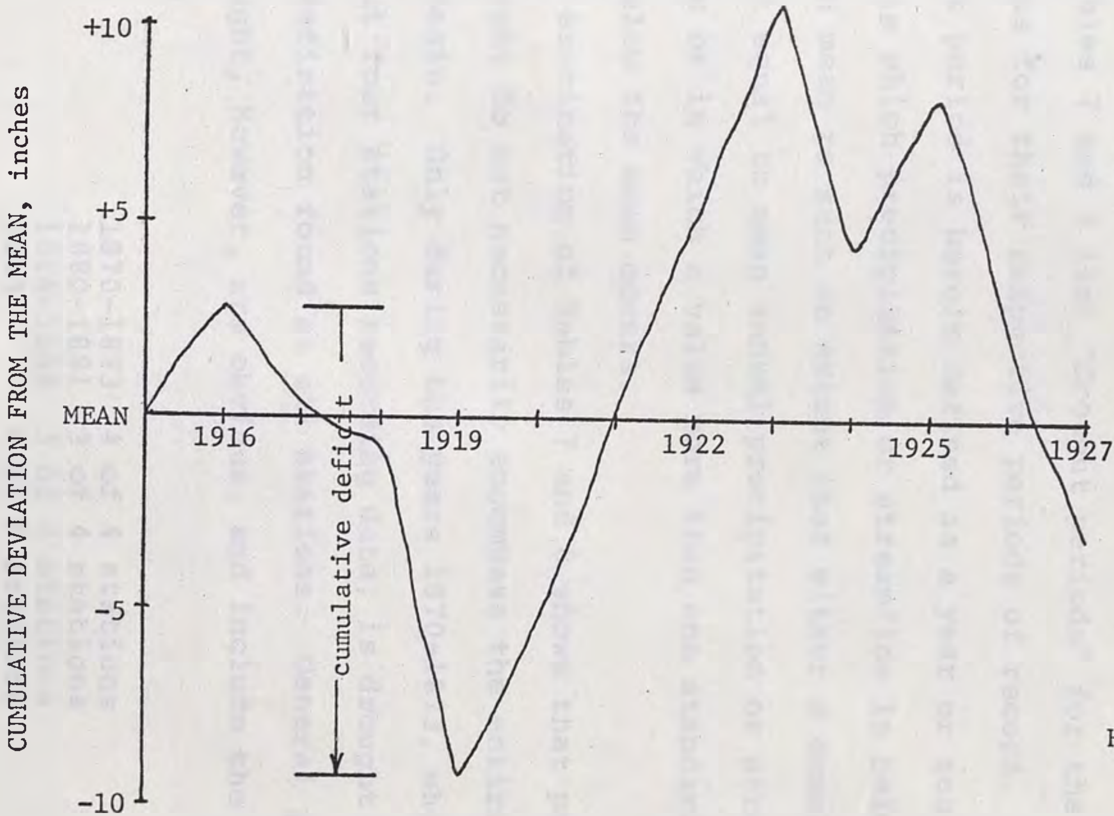
The final statistic in Tables 5 and 6 is a measure of the severity of recorded droughts at the stations. It is calculated by plotting cumulative annual deviations from the mean, measuring the greatest sequential cumulative deficit (drought), and dividing by historic mean annual precipitation. Figure 3 illustrates the calculation of cumulative deviation from the mean and of sequential cumulative deficits. Thus, Elko's most severe drought resulted in a cumulative precipitation deficit equal to 7.75 average years of precipitation. Lamoille's value of 2.11 was the lowest for the study station group.

Similar statistics are given for streamflow in Table 6, although comparisons between stations are less meaningful for streamflow values taken from different points in the same stream network than they are for precipitation values. Means varied from 31.73 cfs at Martin Creek to 367.46 cfs at the Humboldt River Palisade station. Standard deviations varied from 15.88 at Martin Creek to 223.52 at Palisade. At Comus, on the Humboldt main stem, the standard deviation (212.42) was 74% of the mean flow of 286.49 cfs, while at the tributary gages on the South Fork and at Martin Creek, standard deviations were less than 50% of mean flows. Skew valves increased significantly going downstream along the Humboldt, rising from .33 at the mouth of the South Fork to .74 at Palisade and 1.06 at Comus.

Historic low annual mean flows ranged from 8.2 cfs at Martin Creek (1931) to 34.8 cfs at Palisade (1934), while highs ranged from 88.1 at Martin Creek to 950 cfs at Comus. The range of average annual flows in terms of mean flow

FIGURE 3

SAMPLE CALCULATION OF CUMULATIVE DEVIATION FROM THE MEAN



Lamoille Precipitation, 1916-1927

Year	Precip., (inches)	Deviation From Mean	Cum. Dev.
1916	20.74	2.70	2.70
1917	15.46	-2.58	.13
1918	17.17	- .87	- .74
1919	9.55	-8.49	-9.23
1920	22.01	3.97	-5.25
1921	23.48	5.44	.19
1922	23.03	4.99	5.19
1923	23.44	5.40	10.59
1924	11.90	-6.14	4.45
1925	21.74	3.70	8.16
1926	11.80	-6.24	1.92
1927	13.02	-5.02	-3.10

Historic mean = 18.04 inches

was greater for streamflow than for precipitation. At Comus, for instance, the range in recorded mean annual flows was 926 cfs, or 3.2 times the mean annual flow.

The largest cumulative deficits in streamflow were 6.55 times average annual flow at Palisade, 6.52 times annual flow downstream at Comus, 5.82 times on the South Fork, and only 3.78 times at Martin Creek.

DROUGHT PERIODS

Tables 7 and 8 list "drought periods" for the study stations for their respective periods of record. A drought period is herein defined as a year or sequence of years in which precipitation or streamflow is below the station mean to such an extent that either a cumulative deficit equal to mean annual precipitation or streamflow results or in which a value more than one standard deviation below the mean occurs.

An examination of Tables 7 and 8 shows that periods of drought do not necessarily encompass the entire Humboldt Basin. Only during the years 1870-1873, when there were but four stations recording data, is drought by the above definition found at all stations. General periods of drought, however, are obvious, and include the following:

1870-1873	4 of 4 stations
1880-1881	3 of 4 stations
1886-1888	3 of 4 stations
1893	4 of 6 stations

TABLE 7

DROUGHT PERIODS, PRECIPITATION, 1870 - 1976

	Austin	Battle Mt.	Beowawe	Elko	Jiggs	Lamoille	Lovelock	Winnemucca
1870		1870-73 1.3 x	1870-73 1.1 x	1870-83 7.2 x				1871 (beginning of record) - 1873 .8 x
1880		1879-81 .7 x	1880-83 .7 x					
			1885-89 2.0 x	1885-88 1.0 x				1886-89 .8 x
1890	RECORD BEGINS 1890						RECORD BEGINS 1891	
	1895-96 .6 x	1893-96 1.0 x 1898-00 .9 x	1893-00 2.2 x	1892-93 .5 x			1892-00 4.1 x	
1900	1900 .3 x 1902-03 .6 x	1902-03 .5 x 1905 .6 x	1905-06 .7 x		RECORD BEGINS 1910		1902-03 1.2 x 1905-06 1.2 x	1902-03 .6 x
1910	1911 .3 x			1910-11 .6 x		RECORD BEGINS 1916	1910-12 1.2 x	
		1914-22 3.2 x	1915-21 2.2 x					
1920				1918-20 .7 x		1917-19 .7 x	1917 .5 x	1919-21 .6 x

continued

TABLE 7, continued

DROUGHT PERIODS, PRECIPITATION, 1923 - 1976

	Austin	Battle Mountain	Beowawe	Elko	Jiggs	Lamoille	Lovelock	Paradise Valley	Winne-mucca
1923	1926-29 .9 x	1926 .4 x	1924 .4 x	1923-24 .8 x		1924 .3 x	1924 .5 x	RECORD BEGINS 1922	1924 .4 x
			1926-29 1.4 x	1926-29 .9 x	1928-29 .4 x	1926-29 1.1 x		1926 .4 x	1928-29 .9 x
1930			1931-34 1.2 x			1933-35 .5 x	1928-35 1.6 x	1928-31 1.4 x	1931 .4 x
								1933-37 1.0 x	1933 .3 x
								1939 .3 x	
1940									
	1947-56 1.7 x				1947-49 .5 x		1947-48 .6 x	1946-47 .4 x	
1950			1953-55 .7 x		1951-54 1.1 x	1952-54 .7 x			1953-56 1.1 x
	1958-62 1.4 x	1958-61 .9 x	1959-62 .8 x	1958-62 1.0 x	1956-62 1.1 x		1959-60 .6 x		1959-62 .8 x
1960	1966-68 .5 x				1966-67 .5 x RECORD ENDS 1969	1965-66 .4 x RECORD ENDS 1971		1961-62 .6 x	1965-67 .6 x
								1965-66 .7 x	
1970				1974 .5 x					
1976									

Drought periods are followed by an index number representing the cumulative deficit for the period in terms of number of times mean annual flow (denoted by x).

TABLE 8

DROUGHT PERIODS, STREAMFLOW

	Palisade	Comus	South Fork	Martin Creek
1900		1900-1903 1.6 x		
1910	RECORD BEGINS 1912			
	1915-1916 .7 x	1915-1916 1.0 x	1915-1916 1.1 x	
1920	1918-1920 1.5 x	1918-1920 2.1 x		RECORD BEGINS 1922
		1923-1926 1.8 x	1924 .6 x	1923-1926 1.5 x
1930	1926-1931 3.2 x	NO RECORD 1927 TO 1945	1926-1931 3.1 x	1928-1931 1.8 x
	1933-1935 1.8 x			1933-1937 1.5 x
1940	1937-1941 1.2 x			
1950		1947-1950 1.4 x		
	1953-1955 1.8 x	1953-1955 2.1 x	1953-1955 1.7 x	1953-1955 1.4 x
1960	1959-1961 2.2 x	1959-1961 2.4 x	1959-1961 1.9 x	1959-1961 1.3 x
		1963-1964 1.1 x		
	1966-1968 1.1 x	1966-1968 1.2 x	1966-1968 1.1 x	1966 .6 x 1968 .5 x
1970				
1976				

Drought periods are followed by an index number representing the cumulative deficit for the period in terms of number of times mean annual flow (denoted by x).

1895-1896	4 of 6 stations
1900	4 of 6 stations
1902-1903	4 of 6 stations
1905	3 of 6 stations
1919	4 of 8 stations
1924	5 of 9 stations
1926	6 of 9 stations
1928-1929	8 of 9 stations
1933	5 of 9 stations
1953-1954	5 of 9 stations
1959-1962	5 of 9 stations
1966	5 of 9 stations

Within the 1959-1962 period, the following sub-groups are present:

1959-1960	7 of 9 stations
1959-1961	6 of 9 stations
1961-1962	6 of 9 stations

The streamflow records show periods of widespread drought as:

1915-1916	3 of 3 stations
1918-1920	2 of 3 stations
1926	4 of 4 stations
1928-1931	3 of 3 stations
1933-1935	2 of 3 stations
1937	2 of 3 stations
1953-1955	4 of 4 stations
1959-1961	4 of 4 stations
1966-1968	3 of 4 stations, including 4 of 4 in 1966 and 1968

In terms of drought magnitudes, the most severe precipitation shortfall occurred at Elko from the beginning of record in 1870 to 1883, when a net deficit of 7.2 times mean annual precipitation accumulated, or a total of 69 inches. Other notable shorfalls included the Lovelock drought of 1892-1900 (4.1 times mean annual precipitation), the Battle Mountain drought of 1914-1922 (3.2 times annual precipitation), and the Beowawe droughts of 1893-1900 and

1915-1921, both of which resulted in shortfalls of 2.2 times annual precipitation.

The most notable streamflow shortfall occurred from 1926-1931, with deficits of 3.1 times mean annual flow recorded on the South Fork and 3.2 times at Palisade on the Humboldt. Meanwhile, Martin Creek experienced a shortfall of 1.8 times mean flow from 1928-1931. At Comus on the Humboldt, the droughts of 1953-1955 and 1959-1961 resulted in shortfalls of 2.1 and 2.4 times mean annual flow, respectively.

In all of the above exercises, it has been tacitly assumed that all of the data records utilized in the study are free from measurement error.

Estimations of return periods for these droughts will be presented in a later section of this study.

HURST PHENOMENA

H. E. Hurst (1950), in his pioneering study of the long-term storage capacity of reservoirs, set the theoretical amount of reservoir storage needed to yield the average flow of a stream equal to the range from the maximum sum to the minimum sum of the cumulative deviation from the mean of a sequence of streamflows. These range figures are given in Table 10 for the four stations analyzed. They range from 1.7×10^6 acre-feet at Palisade to 87,000 acre-feet at Martin Creek. It should be kept in mind that

TABLE 9

HURST PHENOMENA, PRECIPITATION

	Lamoille	Elko	Winnemucca	Lovelock
Range, R	38 inches	73 inches	27 inches	35 inches
Std. Deviation, s	4.51 "	3.49 "	2.41 "	2.17 "
Number of Events, N	55	107	106	82
K: $\frac{R}{s} = (\frac{N}{2})^K$	.643	.764	.609	.749

Average K = .691 for these four precipitation stations.

TABLE 10

HURST PHENOMENA, STREAMFLOW

	Palisade	Comus	South Fork	Martin Creek
RANGE (theoretical required storage capacity), acre-feet	1.7×10^6	1.3×10^6	5.3×10^5	8.7×10^4
STANDARD DEVIATION, cfs	223.51	212.42	60.01	15.88
N	65	62	69	55
K: $\frac{R}{s} = (\frac{N}{2})^K$	.683	.633	.708	.610

Average K for the four streamflow stations = .659

these figures are designed to provide the mean annual flow from reservoir storage, once the reservoir is filled, for any combination of historical flows. As they are strictly theoretical, they neglect important factors such as evapotranspiration and leakage.

Hurst also investigated the theoretical relationship between this range, R, in cumulative totals, the number, n, of events, and the standard deviation, s, of the events, using the formula $\frac{R}{s} = (\frac{n}{2})^K$. For a variety of events, ranging from tree ring sizes to wheat prices, he found that K averaged 0.72. Table 9 and 10 give computed K values for selected streamflow and precipitation stations. K values for Humboldt Basin streams were found to be .659, 6% less than the .70 value Hurst found in the 33 rivers he analyzed and 9% less than the mean K value of .72 he obtained for all phenomena studied. The values of K calculated for Humboldt Basin precipitation, which averaged .691, corresponded closely with the .70 value Hurst found in his analysis of 168 stations. Although it is not included in the scope of the present investigation, it is felt that the Hurst parameters for precipitation and streamflow as indicated in Tables 9 and 10 will provide useful guidelines for simulation exercises if and when conducted.

RANGES IN STANDARD DEVIATIONS

The distribution of values in terms of the number of standard deviations from the mean is an indication of the form of the skewness of a value set. Tables 11 (precipitation) and 12 (streamflow) group the data for each station in six such standard deviation increments. In the precipitation data, it was found that 40.2% of the values lay between zero and one standard deviation below the mean, while only 29.4% lay within one standard deviation above the mean. 14.6% lay between one and two standard deviations below the mean, compared to 10.9% between one and two standard deviations above the mean. However, only 0.7% of the values fell more than two standard deviations below the mean, while 4.3% of the values were more than two deviations above the mean.

This unequal distribution of precipitation values about the mean is due to two factors. First, since there is a lower limit of zero to precipitation and streamflow values but no upper limit, large values require relatively more small values to balance them about the mean. Second, there is an absolute limit to the number of standard deviations a value can lie below the mean without being negative. In the case of the precipitation data, zero was between 2.25 standard deviations below the mean at Lovelock and 4.64 below at Jiggs. In the streamflow values, which had relatively higher standard deviations, zero fell from 1.35 to 2.10 standard deviations below the mean, and,

TABLE 11

RANGES IN STANDARD DEVIATIONS, PRECIPITATION

	Austin	Battle Mt.	Beowawe	Elko	Jiggs	Lamoille	Lovelock	Paradise Valley	Winnemucca
Number of Standard Deviations Zero is from the Mean	3.63	2.94	2.43	2.56	4.64	4.00	2.25	3.32	3.47
STD. DEV. GROUPS:									
-2.00 or greater	0	0	0	2	1	1	0	0	1
-1.99 to -1.00	11	17	13	16	7	8	15	9	12
-0.99 to -0.01	38	41	47	40	24	19	31	15	43
0 to +0.99	19	35	26	30	14	19	25	15	35
1.00 to 1.99	10	6	6	17	9	6	6	9	12
2.00 or greater	4	6	7	2	2	2	5	1	3
Range in std. dev.:	4.41	5.00	4.53	5.15	4.24	4.51	5.11	4.77	6.32

Average range in standard deviation = 4.89

TABLE 12

RANGES IN STANDARD DEVIATIONS, STREAMFLOW

	Palisade	Comus	South Fork	Martin Creek
Number of Standard Deviations Zero is from the Mean	1.64	1.35	2.10	2.00
STANDARD DEVIATION GROUPS:				
-2.00 or greater	0	0	0	0
-1.99 to -1.00	10	9	13	10
-0.99 to -0.01	27	28	22	22
0 to +0.99	17	15	23	17
1.00 to 1.99	7	8	10	3
2.00 or greater	4	2	1	3
Range in std. deviation	3.77	4.36	4.23	5.03

Average range in standard deviation = 4.35

consequently, no recorded values were found to be more than 1.83 standard deviations below the mean.

16.7% of streamflow values fell one to two standard deviations below the mean, compared to 11.2% in the plus one to two range. 39.4% fell in the zero to minus one range and 28.7% in the zero to plus one range. 4% of the values lay more than two standard deviations above the mean.

The range of values from lowest to highest for a station averaged 4.89 standard deviations for precipitation and 4.35 for streamflow. The highest range in precipitation standard deviations was found at Winnemucca with a range of 6.32, the lowest at Jiggs with a range of 4.24. The largest streamflow range was found at Martin Creek, 5.03, the smallest at Palisade on the Humboldt at 3.77.

RANDOMNESS OF THE DATA

TESTING FOR CYCLES

The randomness of precipitation data has long been a matter of speculation and debate. While many scientists dismiss popular beliefs in drought cycles as mere folklore, others, including researchers at the University of Arizona (Schulman, 1947), claim to have identified drought cycles based on tree ring studies which they in turn link to sunspot cycles. Other researchers point to other evidence of non-randomness. Troxell (1957) found that drought years in southern California occurred in groups. Hurst (1950), in studies of over 1000 years of gage readings for the Nile, found "no obvious periodicity, but there are long stretches when the floods are generally high, and others when they are generally low. These stretches occur without any regularity either in their time of occurrence or duration." Voicing a contrary note, however, Yevjevich (1977) has stated that he considers annual runoff series as independent processes and that (1967) he sees little hope for prediction of drought through extrapolation of past patterns. If precipitation and streamflow events are indeed randomly distributed, and Yevjevich's last statement is true, then there will be no means for us to "predict the future" from the present.

To determine if any cycles are present in the data, serial correlation analysis with lags of one to thirty years was utilized on the two complete (unbroken) precipitation data sets (Elko and Winnemucca) and on the two uninterrupted streamflow data sets (Palisade and Martin Creek). The values so obtained were then plotted in correlograms (Figures 4-7). A number of statistically significant correlation coefficients were found, and have been compiled in Table 13. The complete lists of serial correlation coefficients for the stations are contained in Appendix B.

FIGURE 4

ELKO PRECIPITATION CORRELOGRAM

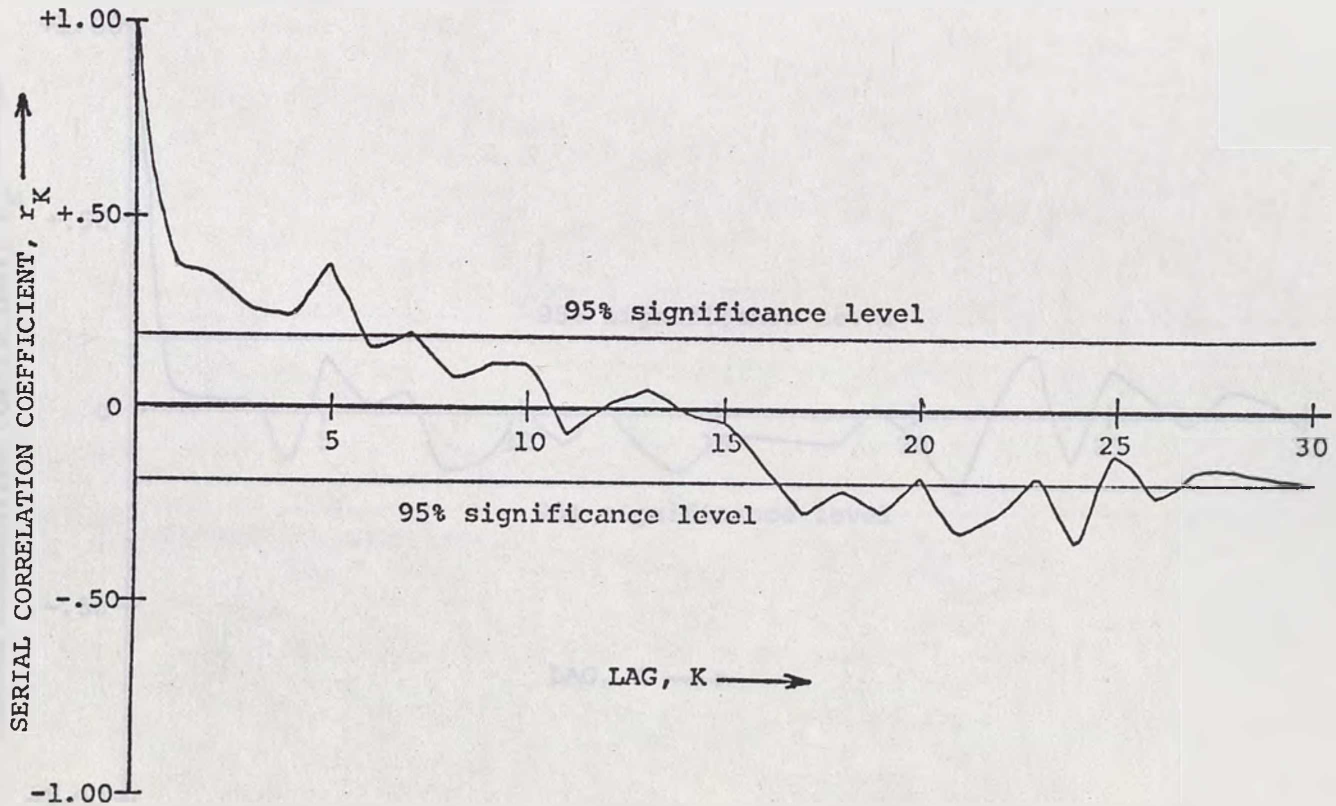


FIGURE 5

WINNEMUCCA PRECIPITATION CORRELOGRAM

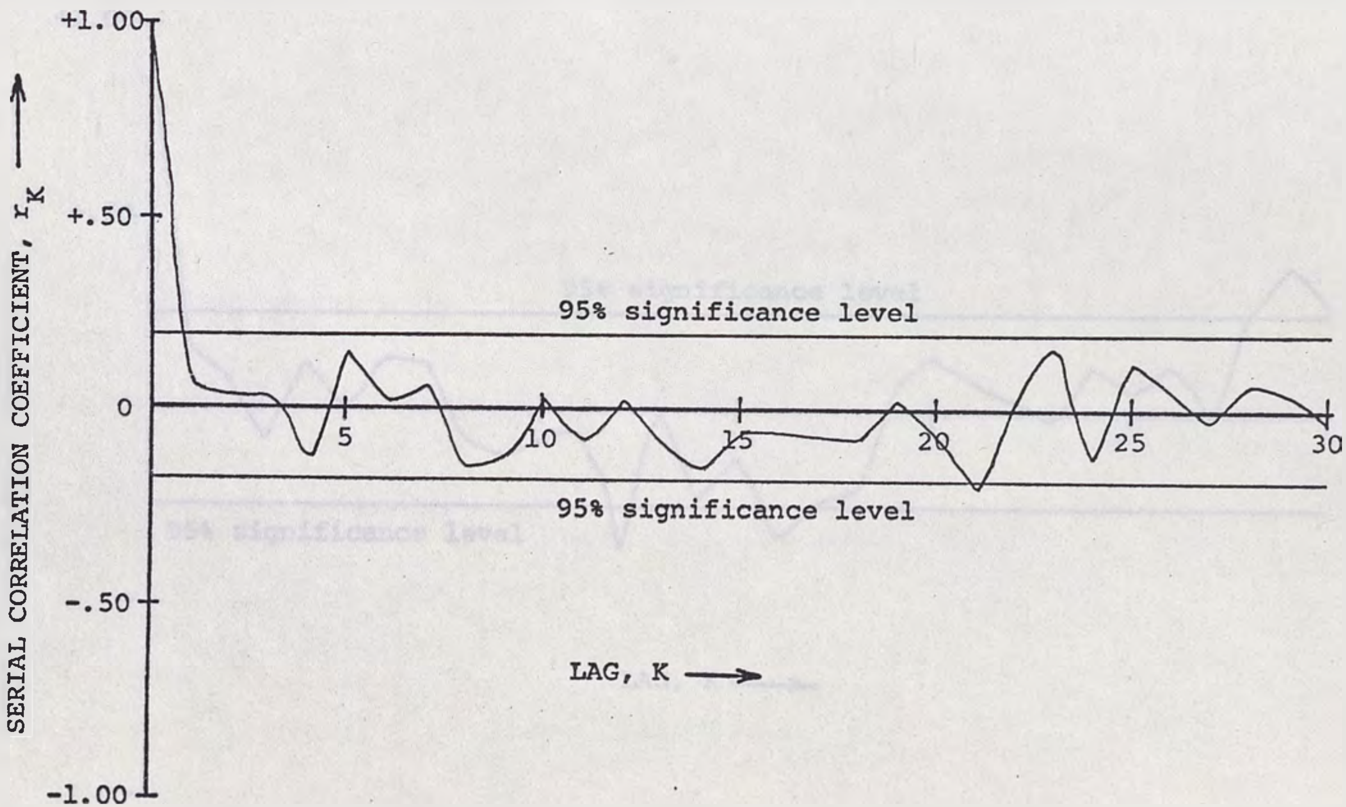


FIGURE 6

PALISADE STREAMFLOW CORRELOGRAM

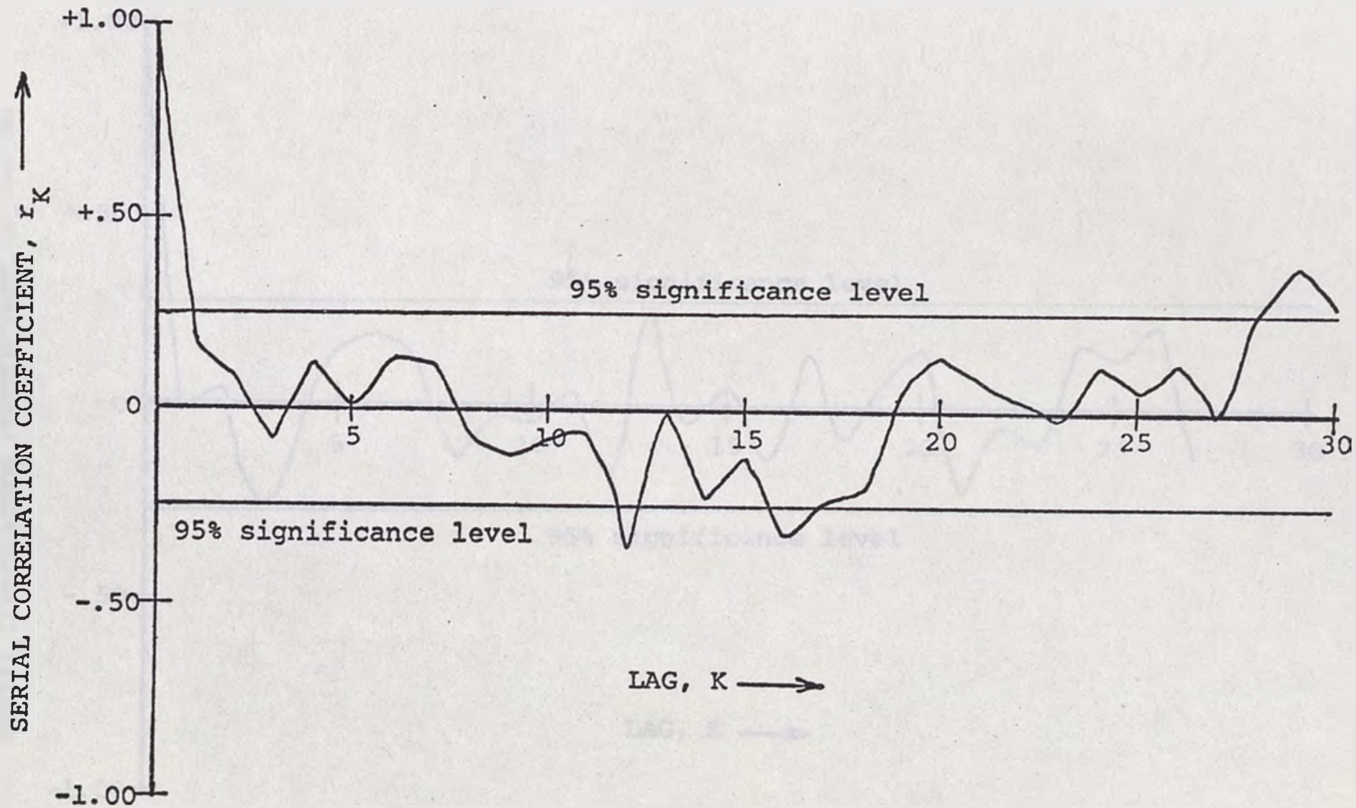


FIGURE 7

MARTIN CREEK STREAMFLOW CORRELOGRAM

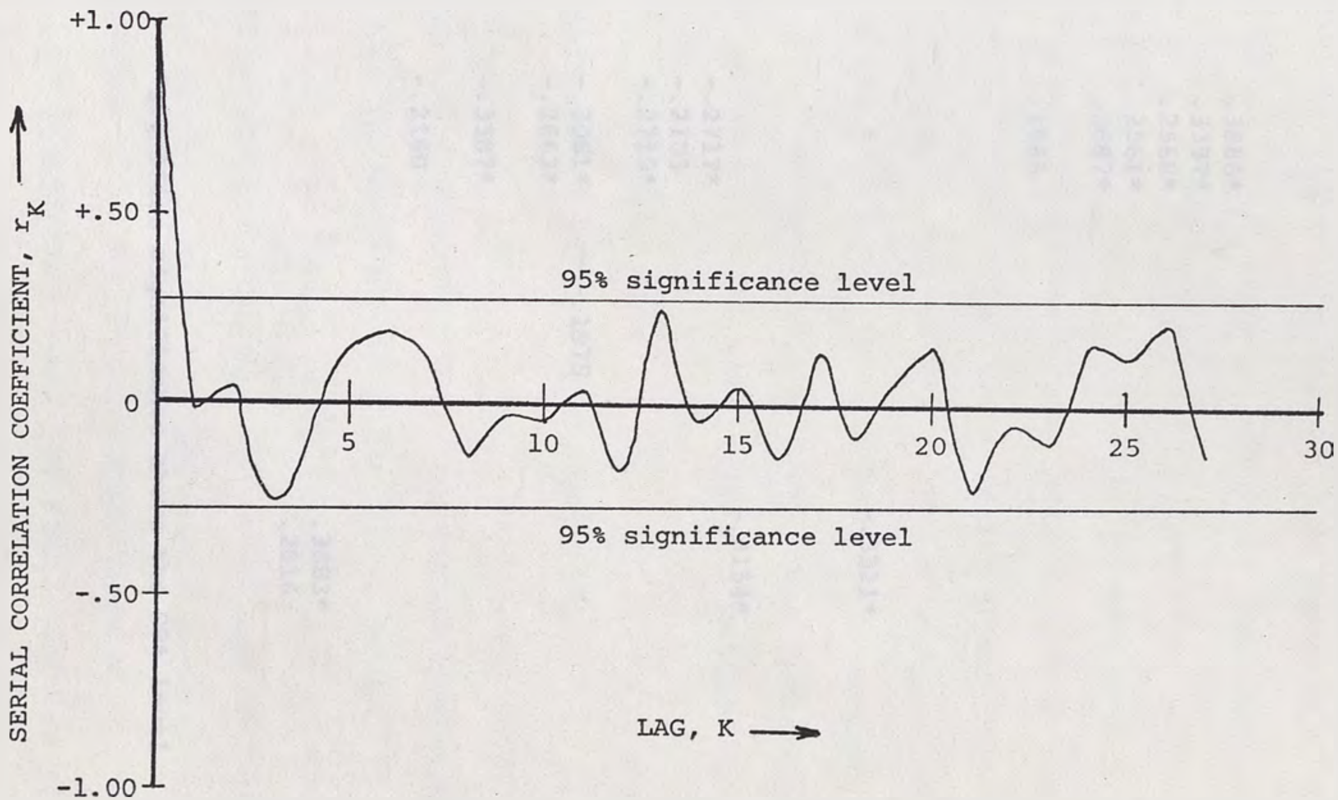


TABLE 13

STATISTICALLY SIGNIFICANT SERIAL CORRELATION COEFFICIENTS

	Elko	Winnemucca	Humboldt R., Palisade	Martin Cr.
Minimum value for statistical significance at 95%	±.1922	±.1931	±.2490	±.2718
LAG:				
1	.3886*			
2	.3397*			
3	.2568*			
4	.2561*			
5	.3687*			
6				
7	.1965			
8				
9				
10				
11				
12			-.3521*	
13				
14				
15				
16			-.3154*	
17	-.2717*			
18	-.2103			
19	-.2719*			
20				
21	-.3081*	-.1975		
22	-.2663*			
23				
24	-.3387*			
25				
26	-.2160			
27				
28				
29			.3883*	
30			.2816	

*signifies significance above the 99% level

CORRELOGRAM ANALYSIS

Visual analysis of the correlograms in Figures 1 to 4 showed varying patterns. The correlogram of Elko precipitation (Figure 4) is Marcovian in form, while the correlogram for Humboldt River streamflow 30 miles downstream at Palisade (Figure 6) appears to contain one cycle with a 29 year length (equal to the maximum length of lag analyzed) on which a random pattern has been superimposed. This difference between the forms of the Elko precipitation and Palisade streamflow correlograms implies little correlation between the two. The correlograms of Winnemucca precipitation (Figure 5) and of Martin Creek streamflow (Figure 7) 45 miles to the north, are both very random in nature. These two correlograms, however, bear similarities in form to each other and thus a correlation between the two might be possible.

STATISTICAL SIGNIFICANCE OF SERIAL CORRELATION COEFFICIENTS

Using Fisher's Z-transform test, the serial correlation coefficient values r_k for lags of 1, 2, 3, 4, 5, 17, 19, 21, 22, and 24 years were found to be significant at the 99% level for Elko precipitation. Lags of 12 and 29 years were found to be significant at the 99% level for Palisade streamflow (Humboldt River). In addition, lags of 7, 18, and 26 years were significant above the 95% level for Elko precipitation, and lags of 16 and 30 years at the 95% level for Palisade streamflow. Only one significant value was found for Winnemucca precipitation, for a lag of 21 years at the 95% significance level. No statistically significant values for any lag were found for Martin Creek streamflow.

The high serial correlation coefficients obtained for lags of 1 to 5 years for Elko precipitation would point to the existence of low precipitation periods (and high precipitation periods) of several years duration. The high value of .3886 obtained for a lag of one year would indicate the likelihood of one extreme year being followed by another. The high values for lags of 17, 18, 19, 21, 22, 24 and 26 years point to a pattern of a loosely-defined cycle in the 107 years of data. Whether or not this cycle will continue in the future cannot be said. It is interesting to note, however, that this cycle is roughly centered around the 22 year average period of the double maximum value of the sunspot cycle. This 22 year cycle is more intense than the 11 year basic sunspot cycle (which in actuality varies from 8 to 16 years) (Rodriguez and Yevjevich, 1968).

Similarly, the high 12 year correlation for Humboldt streamflow at Palisade, which better reflects the basin as a whole, concides roughly with the length of a sunspot cycle, and the only Winnemucca precipitation correlation of significance, that of 21 years, also roughly coincides with the double sunspot maximum.

Finally, the Humboldt River correlations for lags of 29 and 30 years correspond with the popular belief in a 30 year western drought cycle, and support the fact that it has occurred to some extent since the white man came to the Humboldt Basin.

TESTING FOR GROUPINGS OF WET AND DRY YEARS

TURNING POINT ANALYSIS

The next test employed to test for randomness in the data was the turning point test. This test would tend to show the presence of non-random, gradually increasing or decreasing trends in a data set by a lower than normal number of turning points. The four stations analyzed for serial correlations, plus Lamoille Power House precipitation data, were also analyzed for turning points. Table 14 summarizes the results of the turning point test.

According to statistical theory, the number of turning points in a random distribution should be equal to 2/3 (N-2), where N is the number of data points. Elko precipitation was the only data set analyzed which did not have approximately 2/3 (N-2) turning points, falling short of the theoretical 71.4 predicted with only 65 observed. Testing for statistical significance, this value was found to be

TABLE 14

TURNING POINTS TEST RESULTS

	Elko	Winnemucca	Lamoille	Humboldt R. (Palisade)	Martin Creek
Number of Turning Points	65	69.5	38	42	36
N = Number of Yrs.	107	106	55	65	55
2/3(N-2)	70.0	69.3	35.3	42.0	55
Calculated Z	-1.16*	+0.05	+0.88	0.00	+0.23

*significant at the 75% level

significant at only the 75% level, however. Thus, turning point analysis points to only a weak non-random ordering at one of five stations analyzed.

RUNS TEST

The runs test is an alternate method of analyzing randomness in the sequential occurrences of dry (below mean) and wet (above mean) years in a time series. This test was performed on the four stations analyzed for serial correlation. In each instance, the observed number of runs was tested against the expected number of runs for randomness indicated in Table 15. Table 15 shows the results of the runs tests, including the Z values obtained.

A very high value of Z=-3.56 was obtained for Elko precipitation, indicating a non-random grouping of wet and dry years, as illustrated by long runs of dry years followed by long runs of wet years. A value of Z=-1.76 was found for Humboldt River streamflow at Palisade, which is significant at the 92% level. The values calculated for Winnemucca precipitation and Martin Creek streamflow were not statistically significant.

OBSERVED CLUSTERS OF DRY YEARS

As previously stated, many observers have empirically noted the tendency of both dry and wet years to come in groups, particularly in the case of extremely dry years.

TABLE 15

RUNS TEST RESULTS

	Elko	Winnemucca	Palisade	Martin Creek
Z	-3.56	-0.16	-1.76	-0.49
r	43	53	26	26
n_1	58	56	37	32
n_2	59	50	28	23
μ_r	64.96	53.83	32.88	27.76
σ_r	6.16	5.11	3.92	3.57

r = number of runs

n_1 = number of below mean years

n_2 = number of above mean years

$$Z = \frac{r - \mu_r}{\sigma_r}$$

μ_r = mean of the sampling distribution of $r = \frac{2n_1 n_2}{n_1+n_2} + 1$

σ_r = standard deviation of the sampling distribution of r =

$$\left\{\frac{2n_1n_2(2n_1n_2-n_1-n_2)}{(n_1+n_2)^2(n_1+n_2-1)}\right\}^{1/2}$$

Tables 16 and 17 shows the ranks of the year following (sequent year) each of the five driest years of record for precipitation and streamflow stations, respectively. As a means of comparison, the first row of the table gives the ranks of both the median year and the mean year for the station. Years which rank higher than the median, that is, in the wettest half of the ranks for the data set, are denoted by an asterisk. The median year was chosen as the delineation point rather than the mean year since more than half of the years lie below the mean at most stations, although any year ranking below the mean could also be considered a dry year. Twenty-eight of the years immediately following the five lowest precipitation years were in the lower (dry) half of year rankings, while seventeen were in the upper (wet) half. This indicates a tendency for one dry precipitation year to be followed by another dry year. The streamflow data, however, show a nearly even split, with low flow years being followed nine times by below median flows and 10 times by above median flows.

Average rankings for the years sequent to events of rank 1 to 5 are presented in Table 18. Four of the five average sequent year rankings for the nine precipitation stations fall below the median year rank while the fifth falls at the median. The average ranking for the sequent year precipitation group is 31.8, considerably below both the precipitation data's median year's rank of 41.5 and

TABLE 16

SEQUENT RANKS FOR THE FIVE DRIEST YEARS, PRECIPITATION

YEAR OF RANK:	Austin	Battle Mt.	Beowawe	Elko	Jiggs	Lamoille	Lovelock	Paradise Valley	Winnemucca
1	10	3	54*	12	39*	9	17	24	37
2	29	62*	6	90*	5	45*	40	28*	75*
3	35	7	57*	19	1	35*	66*	25*	54*
4	19	67*	10	22	12	29*	5	13	45
5	55*	34	52*	16	7	8	2	1	103*
MEDIAN RANK	41	53	50	54	29	28	41	25	53
MEAN RANK	50	58	61	59	32	29	46	25	56

*signifies that this sequent year lies above the median year of the group in rank

TABLE 17

SEQUENT RANKS FOR THE FIVE DRIEST YEARS, STREAMFLOW

Year of Rank:	Palisade	Comus	South Fork	Martin Creek
1	21	50*	57*	45*
2	45*	58*	8	6
3	7	44*	no record	30*
4	50*	7	14	18
5	4	48*	27	43*

*signifies that this sequent year lies above the median year of the group in rank

TABLE 18

AVERAGE RANKS FOR SEQUENT YEARS

PRECIPITATION

Year	1	followed	by	Year	23
"	2	"	"	"	42*
"	3	"	"	"	33
"	4	"	"	"	30
"	5	"	"	"	31

Average Sequent Rank = 31.8

Median Rank for Group = 41.5

Mean Rank for Group = 46

STREAMFLOW

Year	1	followed	by	Year	43*
"	2	"	"	"	36*
"	3	"	"	"	27
"	4	"	"	"	22
"	5	"	"	"	30

Average Sequent Rank = 31.6

Median Rank for Group = 31.8

Mean Rank for Group = 36

*signifies that this sequent year lies above the median year of the group in rank

mean year's rank of 46. The sequent streamflow ranks are again nearly evenly split. The average sequent year ranking for the streamflow group is 31.60, approximating the streamflow data median's rank of 31.75 but below the streamflow data mean's rank of 36. Thus, there seems to be a definite tendency for a very low precipitation year to be followed by a dry year, but a similar tendency is not evident for streamflow.

Tables 19 and 20 show all clusters of the ten driest years which have occurred. A cluster is defined as two or more of the ten driest years for a station which occur sequentially or with no more than one other year between them. Every station has at least two such clusters. Most striking is the cluster of six of Lamoille's ten driest years in an eight year span of the total record of 56 years. The probability of six or more of the ten driest years in a 56 year record falling withing a period of eight years is .0012 or 0.12%. This indicates that there is slightly more than one chance in a thousand that this is a random distribution. Similarly, the probability that two of the driest ten years will immediately follow one of the driest ten years, as happened at Battle Mountain in 1918-1919-1920, is .0065, or .65%. These clusters are strong evidence of non-random sequential distribution of the driest years and of the tendency for a very dry year to be followed by another very dry year.

TABLE 19

CLUSTERS OF THE TEN DRIEST YEARS, PRECIPITATION

Lovelock 1891-1976	Austin 1890-1976	Battle Mt. 1870-1976	Beowawe 1870-1976	Elko 1870-1976
1892	1900	1870	1887	1872
1893	1902	1871	1888	1874
1894				1875
	1959	1918	1919	
1903	1960	1919	1920	1878
1905		1920		1880
			1931	
			1933	

Jiggs 1910-1969	Lamoille 1916-1971	Paradise Valley 1922-1976	Winnemucca 1871-1976
1947	1924	1926	1928
1948	1926	1928	1929
	1927	1929	1931
1953	1928	1931	1933
1954	1929	1933	
	1931		
1958		1959	
1959		1961	
1960			

TABLE 20

CLUSTERS OF THE TEN DRIEST YEARS, STREAMFLOW

Palisade (1912-1976)	Comus (1895-1926) (1946-1976)	South Fork (1897-1973)	Martin Creek (1922-1976)
1954	1918	1924	1929
1955	1920	1926	1931
1959	1954	1954	1954
1960	1955	1955	1955
1961			
	1959	1959	1959
	1960	1960	1961
	1961		
			1966
			1968

A physical explanation for the clustering of dry years can be hypothesized by linking the persistence of drought for more than one year to the persistence of the Pacific High for more than one year. If the wintertime persistence of this high is indeed due to a shift in ocean temperatures, it would not be unreasonable to assume, given the heat storage capacity of the ocean, that it might take more than one year for ocean temperatures to return to normal and thus allow the Pacific High to dissipate. Thus, with the Pacific High in place for more than one year to block wintertime Pacific storms, more than one dry year would occur in the Humboldt Basin.

DISTRIBUTION FITTING AND RETURN PERIOD ESTIMATION

SUITABLE DISTRIBUTIONS FOR LOW-END EXTREME VALVE DATA SETS

The probability distributions of extreme values (such as those analyzed in this study of drought) are highly skewed and thus require special types of analyses in distribution fitting for return period estimations. A survey of the goodness-of-fit of a large number of types of probability distributions in the low end of hydrologic data sets (drought events) revealed only three types of distributions which are possible candidates for fitting the observed natural events. These three distributions were a log-extremal (Gumbel) type I, log-extremal (Gumbel) type

II, and log-normal (Chow's method). All three of these distributions were then applied to each of the nine precipitation records and the four streamflow records used in this study.

LOG-EXTREMAL (GUMBEL) TYPE I

To fit the log-extremal (Gumbel) type I distribution, (designed for flood flows rather than drought flows), a modification suggested by Velz (1970) was used. This modification consisted of substituting (1-P) for P in the probability equation $P(x)=e^{-e^{-y}}$, where P is the Kimbal frequency and y is the Gumbel reduced variate, then plotting the log of the observed event versus the value of y obtained on special Gumbel extreme probability paper. This modification reverses the slope of the curve and orders drought events by increasing severity to the right of the special probability paper rather than to the left. This modification, however, precludes the fitting of a theoretical curve to the data set. Thus, the drought event values (all values with reduced variates "y" greater than 2.0) were plotted and a straight line curve was then fitted to the points to develop the type I data used in this section. This procedure resulted in the best fit of the three distributions employed in all but two of the thirteen cases. Appendix C compares the values obtained by fitting the three distributions with the actual observed values.

LOG-EXTREMAL (GUMBEL) TYPE II

The log-extremal (Gumbel) type II distribution was designed for data sets with a lower bound, such as the lower bound of zero found in streamflow and precipitation events. This distribution is fitted by entering a table with the skew of the data set, taking the values of 1/k, A(k), and B(k) from the table, then solving the following equations:

$$1.\ V = \bar{x} + (s_x)(A(k))$$

$$2.\ E = V - (s_x)(B(k))$$

$$3.\ \overset{*}{x} = \mathrm{EXP}\ ((\ln\ (V-E) - y/k)) + E$$

The values of V and E are entered in equation 3 with selected values of Gumbel's reduced variate y to develop theoretical plotting points $\overset{*}{x}$. A curve (not a straight line) is then drawn through the $\overset{*}{x}$ plotting points on special Gumbel extreme value probability paper (as with the type I distribution) to develop the theoretical curve. This distribution showed good agreement with the observed values, although at 11 of the 13 stations the type I distribution provided a closer fit (the type I distribution was fit to observed, rather than theoretical, points, although by a straight line rather than a curve). At the two stations (Paradise Valley and Martin Creek) where the type II distribution did give a better fit than the type I distribution, the fit was only marginally better (see Appendix C), and by fitting a new type I curve to the data points (this time considering only points with return periods of more than 10 years) a better type I fit was also obtained at these stations. Type II plotting does have the advantage of allowing the fit of a theoretical curve based on the mean, skew, and standard deviation of the sample data, however.

LOG-NORMAL

Log-normal distributions were also fit to the sample data using Chow's method (for a discussion of this method see Chow, 1964, p. 8-17). This distribution fit the general data well (achieving correlation coefficients of .97 to .99 for precipitation and .95 to .97 for streamflow) but invariably gave theoretical values higher than those observed for drought events. For the four streamflow data sets, all low-event theoretical values with frequencies of occurrence of less than 26% were higher than the observed values of the same frequencies (at Comus, all theoretical values with frequencies below 54% were higher than the oberved values). For the nine precipitation stations, all values with frequencies of less than 5% were reported too high by a theoretical log-normal distribution. For the precipitation stations as a group, theoretical log-normal values were higher than all observed values below an average frequency of 16%, ranging from a delineating frequency of 36% at

Lamoille to 5% at Austin and Battle Mountain. Thus, while a log-normal distribution results in a fit with a very high correlation coefficient for a typical hydrologic data set, this fit breaks down for values in roughly the lower 15% of the sample.

Figure 8 compares observed Battle Mountain drought precipitation values to those predicted by the three theoretical distributions. Figure 9 does the same for Comus streamflow.

ESTIMATIONS OF RETURN PERIODS FOR VARIOUS SEVERITIES

Using the log-extremal Gumbel type I distribution, return periods were estimated for annual deficiencies of .25, .50, .75, 1.00, 1.25, 1.50, 1.75, and 2.00 standard deviations below the mean for all thirteen stations. The magnitudes of drought events corresponding to return periods of 5, 10, 25, 50, and 100 years were also estimated using the Gumbel type I curves. Finally, the return period of the lowest recorded event for each station was estimated in the same manner.

Return periods for the ranges of standard deviations below the mean for the nine precipitation stations are given in Table 21, along with estimates of return periods for the lowest recorded precipitation events. Similar information for the four streamflow stations is given in Table 22. The magnitudes of events corresponding to selected return

FIGURE 8: COMPARISON OF THEORETICAL DISTRIBUTIONS WITH OBSERVED VALUES, BATTLE MOUNTAIN PRECIPITATION

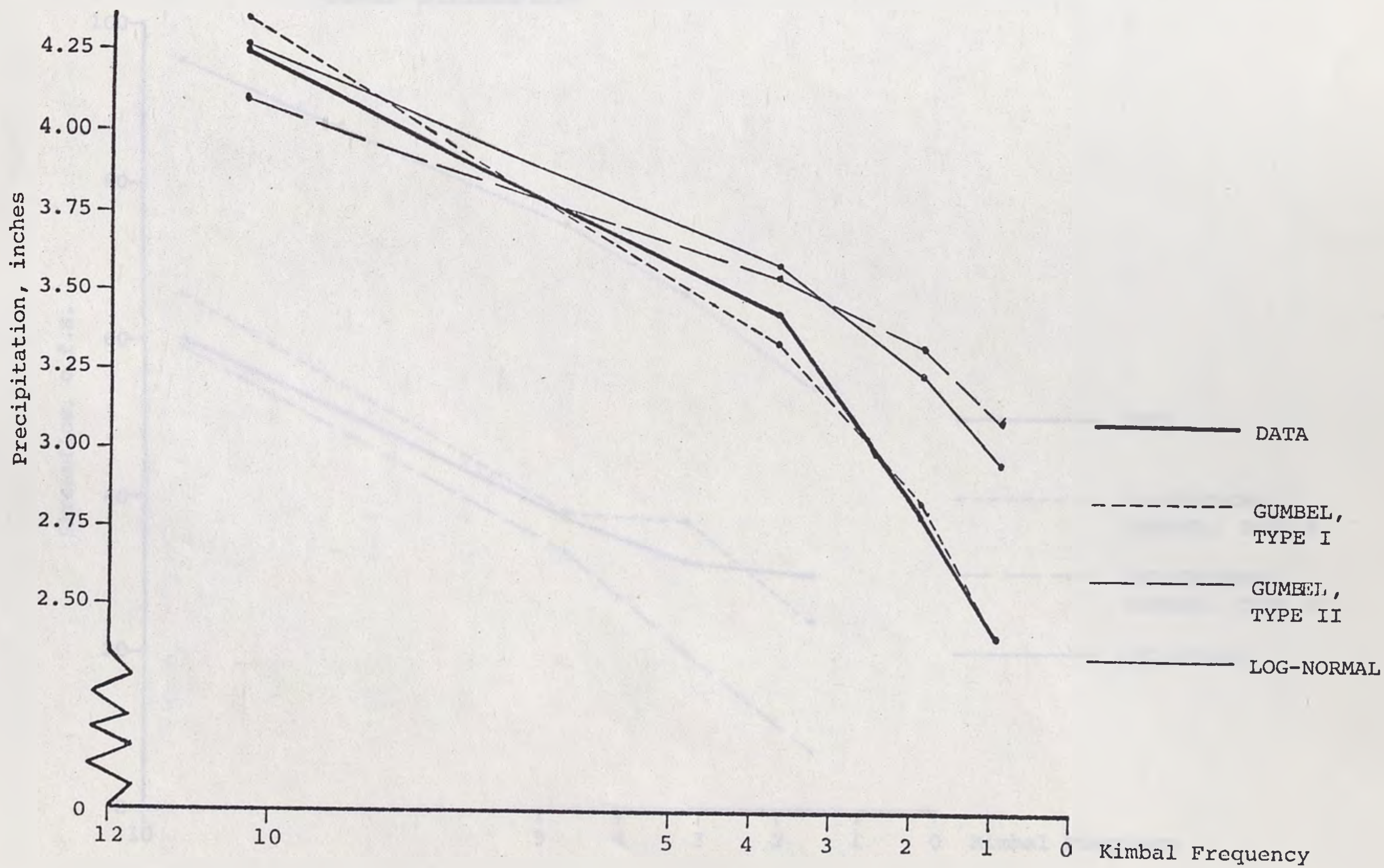


FIGURE 9: COMPARISON OF THEORETICAL DISTRIBUTIONS WITH OBSERVED VALUES, COMUS STREAMFLOW

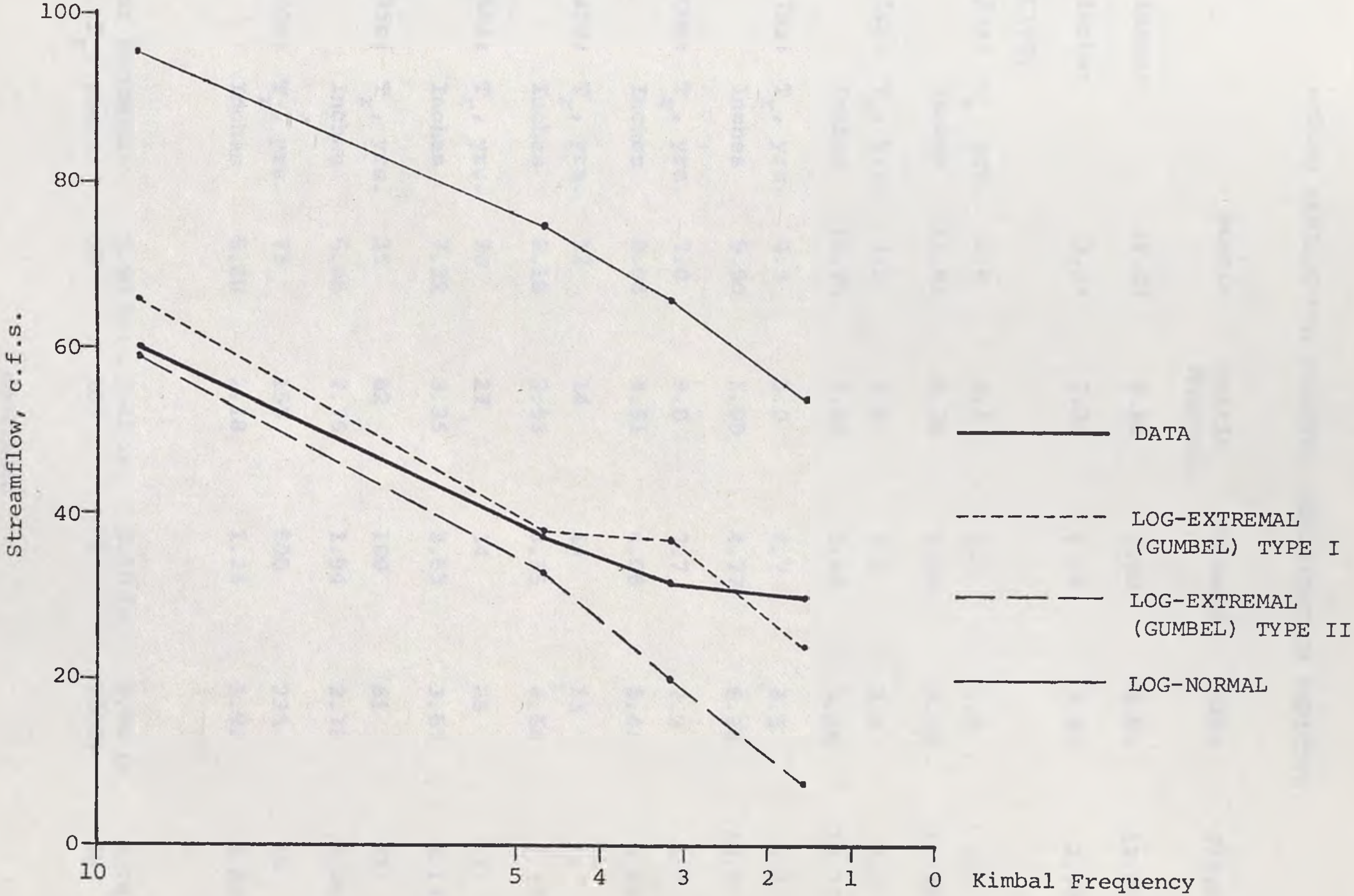


TABLE 21

RETURN PERIODS FOR SELECTED PRECIPITATION DEFICITS

		Austin	Battle Mountain	Beowawe	Elko	Jiggs
$\bar{x}$, inches		12.48	6.84	6.89	8.90	12.01
s, inches		3.44	2.33	2.83	3.49	2.59
DEFICITS:						
-.25s:	T_r, yrs.	2.4	2.5	2.3	2.4	2.3
	Inches	11.62	6.26	6.18	8.03	11.36
-.50s:	T_r, yrs.	3.1	3.5	3.1	3.2	3.0
	Inches	10.76	5.68	5.48	7.16	10.72
-.75s:	T_r, yrs.	4.5	5.0	4.7	4.5	4.3
	Inches	9.90	5.09	4.77	6.28	10.07
-1.00s:	T_r, yrs.	7.0	8.0	7.7	7.2	6.7
	Inches	9.04	4.51	4.06	5.41	9.42
-1.25s:	T_r, yrs.	12	14	14	13	11
	Inches	8.18	3.93	3.35	4.54	8.77
-1.50s:	T_r, yrs.	20	27	34	26	17
	Inches	7.32	3.35	2.65	3.67	8.13
-1.75s:	T_r, yrs.	35	62	100	61	32
	Inches	6.46	2.76	1.94	2.79	7.48
-2.00s:	T_r, yrs.	75	155	500	225	55
	Inches	5.60	2.18	1.23	1.92	6.83
LOWEST RECORDED:		5.90 in.	2.40 in.	2.10 in.	0.94 in.	6.74 in.
T_r, years:		58	105	75	1000+	58

continued

TABLE 21, continued

RETURN PERIODS FOR SELECTED PRECIPITATION DEFICITS

		Lamoille	Lovelock	Paradise Valley	Winnemucca
$\bar{x}$, inches		18.04	4.88	9.15	8.37
s, inches		4.51	2.17	2.76	2.41
DEFICITS:					
-.25s:	T_r, years	2.6	2.3	2.5	2.7
	Inches	16.91	4.34	8.46	7.77
-.50s:	T_r, years	3.3	3.0	3.3	3.5
	Inches	15.79	3.80	7.77	7.17
-.75s:	T_r, years	4.4	4.1	4.6	5.0
	Inches	14.66	3.25	7.08	6.56
-1.00s:	T_r, years	6.5	6.0	7.0	7.1
	Inches	13.53	2.71	6.39	5.96
-1.25s:	T_r, years	9.1	10	11	12
	Inches	12.40	2.17	5.70	5.36
-1.50s:	T_r, years	14	18	18	19
	Inches	11.28	1.63	5.01	4.76
-1.75s:	T_r, years	24	48	35	35
	Inches	10.15	1.08	4.32	4.15
-2.00s:	T_r, years	40	230	70	70
	Inches	9.02	0.54	3.63	3.55
LOWEST RECORDED:		8.80 in.	0.85 in.	4.30 in.	3.13 in.
	T_r, years:	47	82	34	120

TABLE 22

RETURN PERIODS FOR SELECTED STREAMFLOW DEFICITS

		Palisade	Comus	South Fork	Martin Creek
$\bar{x}$, c.f.s.		367.46	286.49	126.27	31.73
s, c.f.s.		223.52	212.42	60.01	15.88
DEFICITS:					
-.25s:	T_r, years	2.1	2.2	2.5	2.1
	c.f.s.	331.6	233.4	111.3	27.8
-.50s:	T_r, years	2.6	2.8	3.2	2.8
	c.f.s.	255.7	180.3	96.3	23.8
-.75s:	T_r, years	3.6	4.3	4.0	3.9
	c.f.s.	199.8	127.2	81.3	19.8
-1.00s:	T_r, years	6.0	9.1	5.8	7.0
	c.f.s.	143.9	74.1	66.3	15.9
-1.25s:	T_r, years	13	57	9.0	18
	c.f.s.	88.1	21.0	51.3	11.9
-1.50s:	T_r, years	70	(negative)	17	41
	c.f.s.	32.2		36.3	7.9
-1.75s:	T_r, years	(negative)	(negative)	49	250
	c.f.s.			21.3	3.9
-2.00s:	T_r, years	(negative)	(negative)	600	(negative)
	c.f.s.			6.3	
LOWEST RECORDED:		34.8 cfs	24.0 cfs	16.3 cfs	8.2 cfs
	T_r, years:	62	47	82	39

periods are given for precipitation in Table 23, for streamflow in Table 24.

These return periods offer a statistical basis for anticipating future shortfalls in supply which can be useful in planning levels of agricultural, industrial, and municipal use.

ESTIMATIONS OF RETURN PERIODS FOR VARIOUS DURATIONS

Annual precipitation and streamflow data for selected stations were examined to determine the ten lowest (non-overlapping) combined annual values for durations of 2, 3, 4, 5, and 10 consecutive years. For each of the five durations, the ten lowest values were then plotted using the Gumbel type I technique, with frequency values P determined by Kimbal's frequency equation with the number of events "n" corresponding to the number of years of data divided by the number of years in the duration being analyzed. It was also necessary to multiply the return period numbers given at the top of a sheet of special Gumbel extreme value plotting paper by the number of years in the duration to obtain return period values corresponding to that duration.

From these plots of multi-year data, return periods were estimated for annual deficiencies of .50, 1.00, 1.50, and 2.00 standard deviations (annual standard deviations for the station multiplied by the number of years in the

TABLE 23

PRECIPITATION VALUES FOR SELECTED RETURN PERIODS

RETURN PERIOD:	Austin	Battle Mountain	Beowawe	Elko	Jiggs	Lamoille	Lovelock	Paradise Valley	Winnemucca
5 Years	9.68	5.10	4.62	6.05	9.78	14.30	2.94	6.89	6.55
10 Years	8.33	4.26	3.74	4.90	8.85	12.18	2.16	5.93	5.53
25 Years	6.96	3.39	2.89	3.67	7.69	9.97	1.43	4.85	4.48
50 Years	6.05	2.86	2.34	3.00	6.96	8.67	1.06	4.31	3.82
100 Years	5.26	2.41	1.92	2.44	6.30	7.39	0.79	3.67	3.25

TABLE 24

STREAMFLOW VALUES FOR SELECTED RETURN PERIODS

all values in c.f.s.

Return Period:	Palisade	Comus	South Fork	Martin Creek
5 Years	161	103	70.1	19.3
10 Years	104	68.0	48.4	13.3
25 Years	60.3	36.6	30.0	10.3
50 Years	39.2	22.4	21.1	8.41
100 Years	26.0	14.4	14.9	6.96

duration). Return periods were also estimated for the lowest value in each duration group. Finally, estimations of the magnitudes of events corresponding to return periods of 10, 25, 50, and 100 years were made.

Three precipitation stations and three streamflow stations were selected for duration analysis based upon their relative lengths of unbroken record and their locations throughout the Humboldt Basin. Results for these stations are given in Table 25 (Elko precipitation), Table 26 (Lovelock precipitation), Table 27 (Winnemucca precipitation), Table 28 (Comus streamflow), Table 29 (Palisade streamflow), and Table 30 (South Fork streamflow).

SUPPLY AND DEMAND ALONG THE HUMBOLDT RIVER MAIN STEM

DEFINITION OF THE PROBLEM

So far in this study, discussion has been confined to an analysis of drought as defined strictly by water supply. Drought, however, involves demand as well as supply, and, by the working definition previously advanced in this study, does not occur until demand exceeds supply. This section of the study attempts to compare supply with demand under certain limiting conditions imposed to insure a meaningful analysis.

Supply-demand analysis has been limited to the Humboldt River main stem below Palisade, due to the large

TABLE 25

ELKO PRECIPITATION DROUGHT DURATION ANALYSIS

DURATION:		2 YEAR	3 YEAR	4 YEAR	5 YEAR	10 YEAR
times $\bar{x}$, inches:		19.6	29.4	39.2	49.0	98.0
times s, inches:		6.98	10.47	13.96	17.45	34.90
DEFICITS:						
-.50s:	T_r, years	4.8	5.1	10	13	28
	Inches	16.11	24.17	32.22	40.28	80.55
-1.00s:	T_r, years	9.2	15	18.8	23	47
	Inches	12.62	18.94	25.24	31.55	63.10
-1.50s:	T_r, years	26	38	54	55	95
	Inches	9.13	13.70	18.26	22.83	45.65
-2.00s:	T_r, years	142	160	232	230	———
	Inches	5.64	8.47	11.28	14.10	
RETURN PERIODS: (values in inches)						
10 Years		12.2	22.0	32.5	43.0	not applicable
25 Years		8.5	15.8	23.3	30.6	87.4
50 Years		7.7	12.4	18.5	23.6	60.3
100 Years		6.3	10.1	14.6	18.5	44.7
LOWEST RECORDED (in.):		5.81	10.19	14.48	19.54	43.42
T_r, years:		136	96	104	87	110

TABLE 26

LOVELOCK PRECIPITATION DROUGHT DURATION ANALYSIS

DURATION:		2 YEAR	3 YEAR	4 YEAR	5 YEAR	10 YEAR
times $\bar{x}$, inches:		9.76	14.64	19.52	24.40	48.80
times s, inches:		4.34	6.51	8.68	10.85	21.70
DEFICITS:						
-.50s:	T_r, years	7.0	11	16	19	57
	Inches	7.59	11.40	15.20	19.02	38.00
-1.00s:	T_r, years	16	24	48	53	330
	Inches	5.42	8.13	10.84	13.55	27.10
-1.50s:	T_r, years	64	78	284	300	______
	Inches	3.25	4.89	6.52	8.15	
-2.00s:	T_r, years	750	600	______	______	______
	Inches	1.08	1.62			
RETURN PERIODS: (values in inches)						
10 Years		6.6	12.0	18.0	24.0	not applicable
25 Years		4.6	8.5	13.2	17.3	46.1
50 Years		3.5	6.1	10.6	14.0	39.0
100 Years		2.4	4.8	8.7	11.4	34.1
LOWEST RECORDED (in.):		2.95	4.48	9.00	11.68	28.89
T_r, years:		80	111	88	90	240

TABLE 27

WINNEMUCCA PRECIPITATION DROUGHT DURATION ANALYSIS

DURATION:		2 YEAR	3 YEAR	4 YEAR	5 YEAR	10 YEAR
times $\bar{x}$, inches:		16.74	25.11	34.48	41.85	83.70
times s, inches:		4.82	7.23	9.64	12.05	24.10
DEFICITS:						
-.50s:	T_r, years	8.6	6.1	11	30	120
	Inches	14.33	21.50	29.66	35.83	71.65
-1.00s:	T_r, years	21	45	57	350	6000
	Inches	11.92	17.88	24.84	29.80	59.60
-1.50s:	T_r, years	71	630	492	_____	_____
	Inches	9.51	14.26	20.02		
-2.00s:	T_r, years	320	_____	_____	_____	_____
	Inches	7.10				
RETURN PERIODS: (values in inches)						
10 Years		13.9	20.6	30.0	39.6	not applicable
25 Years		11.6	18.8	27.0	36.2	77.5
50 Years		10.2	17.7	25.0	34.5	74.4
100 Years		7.9	16.8	23.4	32.6	72.2
LOWEST RECORDED (in.):		9.37	16.69	23.84	32.54	72.80
T_r, years:		78	105	88	105	80

TABLE 28

COMUS STREAMFLOW DROUGHT DURATION ANALYSIS

DURATION:		2 YEAR	3 YEAR	4 YEAR	5 YEAR	10 YEAR
times $\bar{x}$, cfs:		572.98	859.47	1145.96	1432.45	2864.90
times s, cfs:		424.84	637.26	849.68	1062.10	2124.20
DEFICITS:						
-.50s:	T_r, years	6.2	9.3	15	32	62
	cfs	360.6	540.8	721.1	901.4	1802.8
-1.00s:	T_r, years	29	38	460	2000	——
	cfs	148.1	222.2	296.3	370.4	
-1.50s:	T_r, years			all negative		
	cfs					
-2.00s:	T_r, years			all negative		
	cfs					
RETURN PERIODS: (values in cfs)						
10 Years		270	508	821	1212	not applicable
25 Years		159	284	620	953	2490
50 Years		110	185	513	812	1920
100 Years		76	126	428	692	1541
LOWEST RECORDED (cfs):		98	162	478	773	1781
T_r, years		63	66	64	65	63

TABLE 29

PALISADE STREAMFLOW DROUGHT DURATION ANALYSIS

DURATION:		2 YEAR	3 YEAR	4 YEAR	5 YEAR	10 YEAR
times $\bar{x}$, cfs:		734.92	1102.38	1469.84	1837.30	3674.60
times s, cfs:		447.04	670.56	894.08	1117.60	2235.20
DEFICITS:						
-.50s:	T_r, years	5.0	8.4	13	20	40
	cfs	511.4	767.1	1033.8	1278.5	2557.0
-1.00s:	T_r, years	20	27	60	135	170
	cfs	287.9	431.8	575.8	719.7	1439.4
-1.50s:	T_r, years	500+	1000	———	———	———
	cfs	64.4	96.5			
-2.00s:	T_r, years		all negative			
	cfs					
RETURN PERIODS: (values in cfs)						
10 Years		392	692	1164	1669	not applicable
25 Years		260	450	796	1188	3262
50 Years		193	330	614	973	2322
100 Years		145	250	483	788	1755
LOWEST RECORDED, cfs:		187.6	301.3	554.1	893.1	2055
T_r, years		62	60	68	69	68

TABLE 30

SOUTH FORK STREAMFLOW DROUGHT DURATION ANALYSIS

		2 YEAR	3 YEAR	4 YEAR	5 YEAR
DURATION:					
times $\bar{x}$, cfs:		252.54	378.81	505.08	631.35
times s, cfs:		120.02	180.03	240.04	300.05
DEFICITS:					
-.50s:	T_r, years	6.7	9.0	10	19
	cfs	192.5	288.8	385.1	481.3
-1.00s:	T_r, years	13	23	38	68
	cfs	132.5	198.8	265.0	331.3
-1.50s:	T_r, years	74	120	410	600
	cfs	72.5	108.8	145.0	181.3
-2.00s:	T_r, years	all negative			
	cfs				
RETURN PERIODS: (values in cfs)					
10 Years		153	276	388	not applicable
25 Years		96	192	296	441
50 Years		80	148	247	361
100 Years		67	119	209	296
LOWEST RECORDED, cfs:		73.5	135.5	226.8	330.8
T_r, years :		70	66	74	68

number of ungaged or short gage record tributary streams in the Humboldt headwater area above Palisade. Because of the poor tributary flow records, estimation of meaningful drought flows for long return periods for most of these feeder streams was not possible, and thus development of supply-demand relationships was done only for irrigated farmland along the main stem of the Humboldt in the area below Palisade where there are few tributary streams.

The Rye Patch reservoir served as a downstream limit to the study area. This decision was based upon the fact that the reservoir is filled primarily by the unused flow of the Humboldt outside of the growing season or by excess flows during the growing season, and thus irrigation downstream of Rye Patch is not linked closely to growing season flows. Also, it was felt that an analysis of reservoir storage and losses was outside the scope of this paper.

The United States Department of Agriculture (1966) has estimated that 85% of the water consumed along the Humboldt River floodplain below Palisade originates from sources above Palisade. Thus, flow at the Palisade gage is a good guide to the availability of water for use downstream. The only tributaries of note below Palisade are Rock Creek (entering the Humboldt near Battle Mountain), Pole and Little Rock creeks (entering the Humboldt near Golconda), and the Little Humboldt River (entering the river above Winnemucca). As a means of assessing the relative significance of these contributions, the USDA estimated that, in 80% of the years, 116,000 or more acre-feet of water would flow past Palisade, while, downstream, only 2900 acre-feet would be contributed to the flow of the Humboldt by Rock Creek, 2300 acre-feet by Pole and Little Rock creeks, and 3000 acre-feet by the Little Humboldt. These three tributary sources contribute only 8200 acre-feet in an 80% year, or 7.1% of the flow contributed by sources above Palisade. In addition, these small, lower elevation watersheds tend to reach their peak flows earlier in the season than do the contributing mountain tributaries above Palisade, and also tend to dry up during the last part of the growing season in drought years. Thus, their contributions to the irrigation water supply are of even less importance than the acre-feet totals would indicate, and it was felt that ignoring them as sources of supply would not seriously affect the analysis. The USDA (1965) also estimated an inflow of 8000 acre-feet of groundwater into the Humboldt River from the Pole-Little Rock Creek and the Grass Valley watersheds in the vicinity of Winnemucca. Groundwater contributions as such have also been neglected in this analysis. Precipitation, which supplies less than 10% of the growing season water requirements of alfalfa raised along the Humboldt (Mohanna, unpublished data, 1977), was also not considered, being a relatively minor contribution to water needs of crops and roughly paralleling streamflow deficiencies in drought years.

After defining the area of study, the next step was to define the time of study. The USDA (1964) estimated the 28° F. growing season as having an average length of 125 days in the Humboldt bottomland between Beowawe and Comus, or the upper half of the study area. This period coincides roughly with the 123 days of May, June, July and August, and thus these four months were chosen to represent the flow available for effective irrigation. Below the Comus gage, the growing season has been estimated as 140 days at Winnemucca, but due to the availability of data before 1961 in monthly form only the four month growing season flow period was employed here also.

The amount of water available for irrigation along the Humboldt for various drought return periods was calculated in two separate ways, based on two assumptions about the effectiveness and duration of soil moisture storage in irrigated lands. In the first assumption, it was assumed that excess irrigation water added to farm lands in the high flow months of May and June would be retained in usable form as soil moisture for use in the irrigation-need deficit months of July and August. To perform this analysis, the Palisade and Comus flows for the growing season months of May, June, July and August were averaged for each year of record, and a log-extremal (Gumbel) type I distribution was then employed to obtain return periods for average annual growing season flow. It should be noted that the years of record at Palisade (1903-1906, 1912-1976) and the years of record at Comus (1895-1926, 1946-1976) do not coincide and thus comparison between the two stations may be misleading. Table 31 compares the growing season statistics of mean, standard deviation, skew, lowest and highest recorded values, and range of flows in terms of number of standard deviations and number of times mean to similar annual statistics for Palisade and Comus streamflow.

In the second case, it was assumed that soil moisture carry over of surplus irrigation waters would provide a usable source of water to plants for a short time only, and that surplus water applied in May and June would not carry over to make up for July and August deficits. Thus, supplies for each of the four growing season months were considered separately, with the assumption that the lowest flow in the four months set the upper limit on the acreage which could be grown. Again, log-extremal (Gumbel) type I distributions were fit to both Palisade and Comus flow data for each of the four growing season months of May, June, July, and August for the 30 year periods from 1947-1976 (when both stations had complete records) and drought severities for various return periods were extrapolated from these distributions. Table 32 presents the basic statistics for each of the four growing season months at the two

TABLE 31

COMPARISON OF GROWING SEASON AND ANNUAL STREAMFLOW STATISTICS

	$\bar{x}$ (cfs)	s	skew	low flow (year) (cfs)	high flow (year) (cfs)	RANGE Number of Times: s	$\bar{x}$
PALISADE:							
Annual:	367.5	223.5	0.74	34.8 (1934)	877 (1952)	3.77	2.29
Growing season:	621.1	425.8	0.75	8.8 (1934)	1749 (1975)	4.09	2.80
COMUS:							
Annual:	286.5	212.4	1.06	36.8 (1920)	950 (1907)	4.30	3.19
Growing season:	480.8	428.3	1.12	3.8 (1918)	1599 (1975)	3.72	3.32

TABLE 32

MONTHLY GROWING SEASON STATISTICS
(columns same as above)

PALISADE:							
May:	956.4	835.2	1.43	82.8 (1959)	3636 (1952)	4.25	3.71
June:	1198.4	782.6	0.61	77.8 (1954)	3104 (1971)	3.87	2.53
July:	339.0	327.3	1.25	23.8 (1959)	1296 (1975)	3.89	3.75
August:	54.5	50.0	1.81	9.2 (1959)	217 (1965)	4.16	3.82
COMUS:							
May:	671.6	812.2	2.47	31.0 (1959)	4002 (1952)	4.89	5.91
June:	833.9	654.6	1.12	24.9 (1954)	2619 (1971)	3.96	3.11
July:	397.1	395.3	1.20	0.2 (1954)	1475 (1975)	3.73	3.71
August:	52.2	67.6	1.65	0.08 (1954)	241 (1965)	3.57	4.62

stations.

PRESENT DEMAND

Records of water demand are even less precise than records of water supply. The USDA Humboldt River Basin Field Party, in a series of twelve reports dealing with the Humboldt Basin published between 1962 and 1966, estimated consumptive use of water by sub-basins within the Humboldt Basin for 80% supply years. It was possible to extract consumptive use data for the Humboldt main stem between Palisade and Rye Patch from these reports. This data is summarized in Table 33. As municipal use in the study reach was only 3% of irrigation use, and is subject to uncertain future changes, it was not considered. More troublesome, however, are the large consumptive uses attributed to phreatophytes and evaporation along the river (combined, they consume twice the amount of water used for irrigation). As a practical matter, it was necessary to eliminate these also in analyzing drought demand; this deficiency, however, would tend to make the drought flow irrigation acreages overly optimistic, even with the institution of improved management and phreatophyte control.

Since different crops consume different amounts of water, it was necessary to obtain estimates of water consumption for the types of crops most commonly grown in the study area. Such estimates were obtained from unpublished

TABLE 33

CONSUMPTIVE DEMAND IN AN 80% YEAR, PALISADE TO RYE PATCH

units are acre-feet

	Irrigation	Evaporation	Municipal	Phreatophytes
REACH:				
Palisade to Comus*	18,500	2,000	300	29,000
Comus to Rose Creek	9,100	4,500	500	11,000
Rose Creek to Rye Patch	600	—	—	10,000
Total, Palisade to Rye Patch	28,200	6,500	800	50,000
*Sub-reaches:				
Palisade to Battle Mountain	10,700	1,400	300	14,000
Battle Mountain to Comus	7,800	600	—	15,000

data supplied by Dr. Clare Mahannah of the University of Nevada-Reno Department of Plant, Soil, and Water Science. Mahannah found that for the middle section of the Humboldt Basin, alfalfa (the most desirable crop) consumed 3.69 more inches of water than supplied by average rainfall per unit area in May, 6.54 inches more in June, 8.11 inches more in July, and 6.95 inches more in August, or a total of 25.29 inches more than expected rainfall in the four month growing season employed here. Mahannah then estimated farm irrigation efficiency as 50% and canal conveyance efficiency as 85% to come up with a diversion requirement, in c.f.s., necessary to irrigate a one-hundred acre plot of alfalfa. Mahannah's diversion requirements are 1.18 c.f.s. per 100 acres of alfalfa in May, 2.15 c.f.s./100 acres in June, 2.59 c.f.s./100 acres in July, and 2.22 c.f.s./100 acres in August, or an average of 2.04 c.f.s./100 acres over the four month growing season. Less water would be required if farm irrigation and/or canal conveyance efficiencies were increased. It is interesting to note that the 1931 Bartlett Decree, which covers the study area, allows only 0.81 c.f.s./ 100 acres to be removed for Class A water rights, the highest allocation right granted for this stretch of the Humboldt.

Using the USDA figures for irrigation water consumed along the Humboldt between Palisade and Rye Patch in an 80% year (5 year drought), and dividing by Mahannah's estimates for alfalfa irrigation requirements, it is possible to obtain a figure for the alfalfa-equivalent acreage irrigated along the Humboldt in a typical year (it is generally recommended that farmers plant the acreage which can be adequately irrigated in 4 years out of 5, and thus an 80% year can be considered a typical year). This procedure results in an estimated figure of 5,685.4 alfalfa-equivalent acres typically irrigated between Palisade and Rye Patch. 3,729.8 of these alfalfa-equivalent acres lie between Palisade and Comus and the other 1955.6 between Comus and Rye Patch. Using comparative water consumption requirement figures given by the USDA (1966) for the Battle Mountain area, it is estimated that 1.07 times the alfalfa-equivalent acres could be grown in improved meadow and 1.71 times the alfalfa-equivalent acres could be grown in spring grain.

THE ABILITY OF DROUGHT FLOWS TO MEET AGRICULTURAL DEMANDS

Table 34 gives estimated growing season drought flows at Palisade and Comus for return periods of 5, 10, 25, 50, and 100 years and the number of alfalfa-equivalent acres which could be irrigated (completely satisfying the optimum water demands of alfalfa) if all of the estimated flow were diverted for irrigation purposes. Alfalfa-equivalent acreages are also given for mean flows. Similar information is given in Table 35 for Palisade and Comus flows for the separate months of May, June, July, and August. Tables 36 (Palisade) and 37 (Comus) show the percentages of 80%

TABLE 34

GROWING SEASON DROUGHT FLOWS AND
ACCOMPANYING ALFALFA-EQUIVALENT ACREAGES

RETURN PERIOD:		PALISADE	COMUS
5 year:	cfs	125.2	103.5
	acres	6137	4930
10 year:	cfs	106.7	44.7
	acres	5230	2129
25 year:	cfs	44.7	14.9
	acres	2129	709
50 year:	cfs	22.2	6.7
	acres	1088	319
100 year:	cfs	11.8	3.2
	acres	578	150
$\bar{x}$ year:	cfs	621.1	480.8
	acres	30,446	22,895

USDA figures show 5,685.4 alfalfa-equivalent acres being irrigated between Palisade and Rye Patch; 3,729.8 between Palisade and Comus; and 1,955.6 between Comus and Rye Patch.

TABLE 35

MONTHLY GROWING SEASON DROUGHT FLOWS AND ACCOMPANYING ALFALFA-EQUIVALENT ACREAGES

Return Period:		PALISADE May	PALISADE June	PALISADE July	PALISADE August	COMUS May	COMUS June	COMUS July	COMUS August
5 year:	cfs	228	446	56.3	21.3	125	245	49.4	2.0
	acres	19322	20740	2174	959	10610	11381	1907	90
10 year:	cfs	155	217	38.5	15.3	81.4	94.6	9.0	0.17
	acres	13093	10093	1486	689	6898	4400	347	8
25 year:	cfs	93.7	87.4	23.3	10.0	46.1	27.9	1.0	0.08
	acres	7941	4065	900	450	3907	1298	39	4
50 year:	cfs	64.7	43.0	16.1	7.2	30.0	11.0	0.2	0.05
	acres	5483	2000	622	324	2542	512	8	2
100 year:	cfs	45.1	22.0	11.2	5.3	20.1	4.5	0.08	0.03
	acres	3822	1023	432	239	1703	209	3	1
$\bar{x}$ year:	cfs	956.4	1198.4	339.0	54.5	671.6	833.9	397.1	52.2
	acres	81051	55740	13089	2455	56915	38786	15332	2351
cfs/100 acres:		1.18	2.15	2.59	2.22	1.18	2.15	2.59	2.22

USDA figures show 5,685.4 alfalfa-equivalent acres being irrigated between Palisade and Rye Patch; 3,729.8 between Palisade and Comus; and 1,955.6 between Comus and Rye Patch.

TABLE 36

PERCENTAGES OF IRRIGATION DEMAND FULFILLED FOR VARIOUS RETURN PERIODS

PALISADE

Return Period:		May	June	July	August	Growing Season
5 year:	a)	187	200	34	2	108
	b)	284	305	51	2	165
10 year:	a)	121	77	6	negligible	92
	b)	185	118	9	"	140
25 year:	a)	69	23	1	"	39
	b)	105	35	1	"	59
50 year:	a)	45	9	negligible	"	19
	b)	68	14	"	"	29
100 year:	a)	30	4	"	"	10
	b)	46	6	"	"	15
$\bar{x}$ year:	a)	1001	682	270	41	536
	b)	1526	1040	411	63	816

a) Palisade to Rye Patch demand
b) Palisade to Comus demand

TABLE 37

PERCENTAGES OF IRRIGATION DEMAND FULFILLED FOR VARIOUS RETURN PERIODS

COMUS

Return Period:	May	June	July	August	Growing Season
5 year:	543	582	98	5	252
10 year:	353	225	18	negligible	109
25 year:	200	66	2	"	36
50 year:	130	26	negligible	"	16
100 year:	87	11	"	"	8
$\bar{x}$ year:	2910	1983	784	120	1171

Demand is for irrigation between Comus and Rye Patch.

year agricultural demand met by the estimated quantities of irrigation water available for selected return periods during each month of the growing season and for the growing season as a whole. Table 36 (Palisade) shows first the percentage of irrigation demand met for the Palisade to Rye Patch stretch of the Humboldt as a whole and second the percentage of Palisade to Comus demand met. Table 37 (Comus) shows the percentage of irrigation demand between Comus and Rye Patch which could be met if all water passing Comus were utilized for irrigation.

Comparison of Tables 34 and 35 shows that grouping the growing season flows provides hypothetical 5-year drought return period acreage figures which better agree with the USDA's 80% year acreage figures than do the figures obtained for the individual months in Table 35. It is likely, then, that the number of acres of successful irrigated crops is not absolutely limited by the available irrigation water in the lowest month (August) of the growing season, and that until the major uncertainties of phreatophyte and evaporative consumption can better be dealt with, an analysis based on growing season, flows rather than month-by-month flows, would be satisfactory.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Serial correlation coefficients for eastern Humboldt Basin precipitation at Elko and Humboldt River streamflow at Palisade are statistically significant at lags which may indicate loosely defined cycles of approximately 41 and 29 years, respectively. This cyclical behavior in the headwaters area, however, is not strong enough to accurately predict future droughts and is not evident in the western part of the basin. It appears that the best hope for prediction of future droughts lies in establishing a correlation of sufficient lead time between ocean temperatures in the North Pacific and west coast precipitation.

The high values obtained for serial correlation coefficients for Elko precipitation at all lags of 1 to 5 years, the results of the runs test for Elko precipitation data, the striking clusters of lowest historic event years observed at all stations, and the low average ranks of years sequent to very dry years all point to a non-random grouping of dry years for precipitation and a tendency for one very low precipitation year to be followed by another. This phenomenon is evidenced in the streamflow data only by the presence of clusters of very dry years, perhaps because of the delayed effect of subsurface discharges to the river.

The log-extremal (Gumbel) Type I distribution was found to give the best fit for the observed drought-event data for both precipitation and streamflow. As the method of fitting this distribution does not allow for the fitting of a theoretical curve, it is recommended that the log-extremal (Gumbel) Type II distribution be used if a theoretical curve is desired.

RECOMMENDATIONS

Based on the investigation reported herein, it is recommended that the following tasks be investigated to aid future workers in the drought field:

1. Explore the relationship between ocean temperatures in the North Pacific and west coast rainfall.
2. Delineate the precipitation component contributions over a significant period of record for selected Humboldt Basin stations and the respective component deficiencies during major drought periods.
3. Perform harmonic analysis and range analysis on Elko precipitation data and Palisade streamflow data.
4. Increase the gage density in the basin, particularly the precipitation gage density and the coverage of Humboldt River tributaries in the headwaters area.

5. Delineate the growing season (period of agricultural irrigation water demand) more clearly in order to identify water supply-demand interactions.

Based on the findings of this investigation regarding the tendency for one very dry year to be followed by another dry year, it is recommended that officials in charge of drought planning institute water conservation measures at the end of any snow season which has resulted in an abnormally light snowpack.

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APPENDIX A

FACTORS FOR CONVERTING ENGLISH UNITS TO METRIC UNITS

Multiply English Unit	by	To Obtain Metric Unit
inches	2.54×10^{-2}	meters
feet	3.048×10^{-1}	meters
miles	1.609×10^{0}	kilometers
acres	4.047×10^{-1}	hectares
	4.047×10^{-3}	square kilometers
square miles	2.590×10^{0}	square kilometers
acre-feet	1.233×10^{3}	cubic meters
cubic feet per second	2.832×10^{1}	liters per second
	2.832×10^{-2}	cubic meters per second

APPENDIX B: SERIAL CORRELATION COEFFICIENTS

ELKO PRECIPITATION, 1870-1976

LAG	SERIAL CORRELATION COEFFICIENT
1	.3886
2	.3397
3	.2568
4	.2561
5	.3687
6	.1730
7	.1965
8	.0966
9	.1175
10	.1090
11	-.0689
12	.0250
13	.0577
14	.0007
15	-.0265
16	-.1523
17	-.2717
18	-.2103
19	-.2719
20	-.1859
21	-.3081
22	-.2663
23	-.1818
24	-.3387
25	-.1065
26	-.2160
27	-.1684
28	-.1531
29	-.1715
30	-.1825

WINNEMUCCA PRECIPITATION, 1871-1976

LAG	SERIAL CORRELATION COEFFICIENT
1	.0633
2	.0290
3	.0262
4	-.1206
5	.1567
6	.0193
7	.0641
8	-.1464
9	-.1185
10	.0148
11	-.0854
12	.0181
13	-.0935
14	-.1572
15	-.0584
16	-.0593
17	-.0725
18	-.0749
19	.0145
20	-.0634
21	-.1975
22	.0203
23	.1690
24	-.1239
25	.1184
26	.0541
27	-.0179
28	.0737
29	.0433
30	-.0362

PALISADE STREAMFLOW, 1912-1976

LAG	SERIAL CORRELATION COEFFICIENT
1	.1833
2	.0860
3	-.0877
4	.1146
5	.0091
6	.1276
7	.1159
8	-.0730
9	-.1148
10	-.0853
11	-.0657
12	-.3521
13	-.0106
14	-.2299
15	-.1274
16	-.3154
17	-.2477
18	-.2027
19	.0550
20	.1327
21	.0820
22	.0334
23	-.0233
24	.1045
25	.0503
26	.1179
27	-.0064
28	.2424
29	.3883
30	.2816

MARTIN CREEK STREAMFLOW, 1922-1976

LAG	SERIAL CORRELATION COEFFICIENT
1	-.0143
2	.0397
3	-.2517
4	-.0541
5	.1651
6	.1905
7	.1074
8	-.1273
9	-.0305
10	-.0337
11	.0304
12	-.1727
13	.2478
14	-.0452
15	.0529
16	-.1445
17	.1301
18	-.0969
19	.0628
20	.1547
21	-.2133
22	-.0614
23	-.1014
24	.1604
25	.1185
26	.2161
27	-.1138

Due to the brevity of Martin Creek record, only 27 lags (1/2 N) were performed.

APPENDIX C

COMPARISON OF OBSERVED DATA WITH FITTED DISTRIBUTIONS

PRECIPITATION

	Observed Value	Kimbal Frequency	Gumbel Type I	Gumbel Type II	Log-normal
AUSTIN	8.47	10.84	8.50	8.58	8.61
(inches)	6.40	3.61	6.75	7.10	7.39
	6.34	2.41	6.30	6.75	7.04
	5.90	1.20	5.47	6.30	6.50
BATTLE MOUNTAIN	4.25	10.38	4.35	4.10	4.27
	3.43	3.77	3.35	3.56	3.59
(inches)	2.80	1.89	2.83	3.29	3.25
	2.40	0.94	2.39	3.11	2.97
BEOWAWE	3.74	10.00	3.74	3.63	3.83
(inches)	2.50	4.00	2.89	3.03	3.18
	2.17	2.00	2.36	2.80	2.82
	2.10	1.00	1.93	2.61	2.52

	Observed Value	Kimbal Frequency
ELKO	4.77	10.18
(inches)	3.93	3.70
	1.39	1.85
	0.94	0.93
JIGGS	9.14	10.34
(inches)	8.11	5.17
	7.60	3.45
	6.74	1.72
LAMOILLE	11.90	10.71
(inches)	10.87	5.36
	9.55	3.57
	8.80	1.79
LOVELOCK	2.45	9.64
(inches)	1.33	3.61
	1.20	2.41
	0.85	1.20

Gumbel Type I	Gumbel Type II	Log-normal
4.95	4.57	5.11
3.60	3.32	4.20
2.92	2.66	3.74
2.36	2.33	3.37
8.94	8.76	8.97
8.00	8.00	8.29
7.54	7.69	7.96
6.82	7.17	7.47
12.43	12.30	12.88
10.59	10.80	11.75
9.78	10.07	11.21
8.50	9.03	10.41
2.10	2.27	2.56
1.38	1.70	2.07
1.16	1.54	1.92
0.85	1.31	1.70

	Observed Value	Kimbal Frequency	Gumbel Type I		Gumbel Type II	Log-normal
PARADISE VALLEY	5.53	10.00	5.81	5.93*	5.75	6.00
	4.89	4.00	4.66	4.85*	4.95	5.22
(inches)	4.30	2.00	3.94	4.31*	4.57	4.77

*Values resulting from a secord type I fit employing only values with frequencies less than 10.00

WINNEMUCCA	5.75	10.28	5.58	5.53	5.62
(inches)	4.51	3.74	4.39	4.95	4.85
	3.85	1.87	3.82	4.62	4.45
	3.13	0.94	3.19	4.48	4.12

STREAMFLOW

	Observed Value	Kimbal Frequency	Gumbel Type I		Gumbel Type II	Log-normal
COMUS	60.2	9.52	66.0		59.1	95.8
(c.f.s.)	38.0	4.76	37.3		33.1	75.0
	36.8	3.17	31.8		20.1	66.0
	24.0	1.59	19.9		7.4	54.0
PALISADE	123.0	10.61	107		105	155
(c.f.s.)	78.3	4.55	63.4		54.6	120
	51.1	3.03	49.4		39.3	108
	34.8	1.52	33.1		13.5	91.5
MARTIN CREEK	13.9	10.71	14.6	13.7*	14.2	15.7
(c.f.s.)	11.9	5.36	11.0	11.3*	11.6	13.2
	11.6	3.57	8.3	10.1*	11.0	12.0
	8.2	1.79	7.1	8.3*	9.8	10.4
SOUTH FORK	44.3	10.00	48.4		49.4	63.8
(c.f.s.)	34.8	4.29	31.2		30.0	52.2
	24.4	2.86	25.0		22.2	48.0
	16.3	1.43	17.6		13.5	42.1

*Values resulting from a second Type I fit employing only values with frequencies less than 10.00